National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

June 18, 2019

Reply to attn. of: Office of Communications

Ms. Jamie Corey
Senior Researcher
Documented
P.O. Box 258084
Madison, WI 53725

Re: FOIA Tracking Number 19-HQ-F-00389

Dear Ms. Corey:

This is the final response to your Freedom of Information Act (FOIA) request to the National Aeronautics and Space Administration (NASA), dated and received in this office on March 26, 2019. You seek the following records that were created or obtained by NASA between January 1, 2019, and the date the records search is conducted:

1) Records pertaining to the Presidential Committee on Climate Security (PCCS), including but not limited to records regarding the Deputies Committee Meeting on the Presidential Committee on Climate Security that took place on February 22, 2018; and
2) Communications between James Bridenstine, and William Happer, Patrick Moore, or any member or representative of the CO2 Coalition.

Our interim response, dated May 8, 2019, summarized our work on your request thus far. It also provided you with 57 pages of records obtained from our search within ITCD, and advised that we would provide you with another response once our review of records located in the Office of Interagency and Intergovernmental Relations (OIIR) is complete. That review is now complete and remaining records from ITCD as well as OIIR are enclosed.

Please note that the enclosed records include communications originating from the National Security Council (NSC), a component of the White House that is not subject to the FOIA. Although these communications from the White House do not constitute "agency records" that are subject to FOIA, NASA consulted with the NSC in an effort to release to you as much information as possible. Thus we, in consultation with the NSC, reviewed under the FOIA the responsive records to determine whether they may be accessed under the FOIA's provisions. Based on that review, this office is providing the following:

__50__ page(s) are being released in full (RIF);
__10__ page(s) are being released in part (RIP);
__10__ page(s) identified as non-agency records per consultation with NSC.

NASA redacted from the enclosed documents certain information pursuant to the following FOIA exemptions:

Exemption 6, 5 U.S.C. § 552(b)(6)

Exemption 6 allows withholding of "personnel and medical files and *similar files* the disclosure of which would constitute a clearly unwarranted invasion of personal privacy." 5 U.S.C. § 552(b)(6)(emphasis added). NASA invokes exemption 6 to protect the names of private individuals, as well as email addresses and other contact information of third parties referenced in these records.

Appeal

You have the right to appeal my action on your request. Please send any appeal to:

Administrator
NASA Headquarters
Executive Secretariat
ATTN: FOIA Appeals
MS 9R17
300 E Street S.W.
Washington, DC 2054

Both the envelope and letter of appeal should be clearly marked, "Appeal under the Freedom of Information Act." You must also include a copy of your initial request, the adverse determination, and any other correspondence with the FOIA office. In order to expedite the appellate process and ensure full consideration of your appeal, your appeal should contain a brief statement of the reasons you believe this initial determination should be reversed.

Assistance and Dispute Resolution Services

For further assistance and to discuss any aspect of your request you may contact NASA's Principal FOIA Officer, Nikki Gramian, via telephone at 202-358-0625 or via e-mail at Nikki.N.Gramian@NASA.gov. You may also send correspondence to Ms. Gramian at the following address:

Freedom of Information Act Office
National Aeronautics and Space Administration
NASA Headquarters
300 E Street, S.W., 5P32
Washington D.C. 20546
Fax: 202-358-4332

Additionally, you may contact the Office of Government Information Services (OGIS) at the National Archives and Records Administration to inquire about the FOIA mediation services it offers. The contact information for OGIS is as follows:

Office of Government Information Services
National Archives and Records Administration

8601 Adelphi Road-OGIS
College Park, Maryland 20740-6001
Email: ogis@nara.gov
Telephone: 202-741-5770
Toll free: 1-877-684-6448
Fax: 202-741-5769

Important: Please note that contacting any agency official including the undersigned, NASA's Principal FOIA Officer, and/or OGIS is not an alternative to filing an administrative appeal and does not stop the 90 day appeal clock.

Sincerely,

Stephanie K. Fox

Stephanie K. Fox
Team Lead / Chief FOIA Public Liaison

Enclosures

Re: Daily on Energy, presented by GAIN: Rift grows in GOP over climate change ... Greens celebrate Endangered Species Day

From:	Thomas Wysmuller <tom@colderside.com>
To:	William Happer <[redacted]>
Cc:	Bridenstine James <james.f.bridenstine@nasa.gov>, Singer S. Fred <[redacted]>, Bridenstine, James F. (HQ-AA000) </O=NASA/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=Bridenstine, James F 8724750558df>
Sent:	May 19, 2018 11:12:32 AM EDT
Received:	May 19, 2018 11:12:44 AM EDT

Hi, Wil:

I'll embed my reaction within your e-mail

On May 19, 2018, at 8:27 AM, William Happer [redacted] <mailto[redacted] > wrote:

Dear Tom,

Thanks for the assessment. With repect to Fred Singer's WSJ Op Ed, I was surprised to read what seemed to be a statement that the rate of sea level rise is "accelerating." I don't see that in the tide gauge data. Neither do I. Could this be another editorial improvement? Quite likely. Fred told me he is limited to typing with only one hand, and was having a difficult time doing so. I asked him to send me the final WSJ submission (that I was originally supposed to get prior to its delivery), and he thinks it may have been accidentally erased. Some of the "factoids" that I talked to Fred about ended up in his thinking, but the floating Ross Ice Shelf contributing to SLR was not one of them. He did use some of the Zwally paper's conclusions, but reference to it was either omitted or deleted by the WSJ.

And how Bridenstein or anyone else can say that humans are a major cause of warming is a puzzle to me. I'll go along with humans playing a major role in the increase of CO2 in the atmosphere, from a relatively steady 280ppm for the past two thousand years +, to over 400ppm, starting in the late 1700s, but oceanic warming did not follow at anything near the CO2 increase rate. Whatever warming we have had over the past 50 or so years is indistinguishable from many previous warmings. You are absolutely correct!!! Per EPICA and Vostok, the past three interglacials each were warmer than the present, and there were no factory or transportation emissions helping boost temperatures along back then.

I still believe Jim Bridenstine was trying to diffuse what is essentially a non mission-critical issue, as the Potomac estuary will not inundate NASA Headquarters anytime soon, or within anyone's lifetime either. NASA is an agency far different than the one I worked in during the Apollo days, and the challenge Jim faces will be getting it back to a no-nonsense, measured and validated data orientation. Catastrophic SLR and runaway temperature rise is part of the nonsense, and he will be wise to systematically sidestep it for the short term.

Tom

Will

______

From: Thomas Wysmuller [tom@colderside.com <mailto:tom@colderside.com>]
Sent: Saturday, May 19, 2018 3:40 AM
To: William Happer
Cc: Bridenstine James; Singer S. Fred

Subject: Re: Daily on Energy, presented by GAIN: Rift grows in GOP over climate change ... Greens celebrate Endangered Species Day

Hi, Wil:

No real “insight,” but here’s my short reaction to a Newsweek piece - same subject - in the comments at the end.

< http://www.newsweek.com/climate-change-skeptic-bridenstine-tells-nasa-he-believes-human-caused-global-931585 >

He’s entered a hornets nest without a smoke pot and I hope will methodically let the NASA “hive” settle down. There is much to do there, major mission critical work in fact, and having a climate oriented disruption during his first month is not in his, or the nation’s, best interest. My guess is that he intelligently quickly read the “lay of the land” and is acting accordingly.

I do intend to eventually see Jim Bridenstine at some time in the next month or so, but well after the NY climate conference where I’ll be with b6 [redacted] next week.

On another issue, Fred Singer was going to collaborate with me on an article he was putting together for the WSJ, but for some reason went at it on his own. According to a phone conversation I had with Fred earlier tonight, the WSJ severely edited it, and the usual suspects are jumping all over it, to Fred’s dismay.

Best to you, Wil, and I hope you don’t mind the ccs!

Tom

PS No bccs

On May 18, 2018, at 11:05 PM, William Happer b6 [redacted] <mailto b6 [redacted]> > wrote:

Dear Tom,

Do you have any insight about the remarks attributed to Bridenstine below?

Will

Begin forwarded message:

From: Washington Examiner <news@washingtonexaminer.com <mailto:news@washingtonexaminer.com> >

Subject: Daily on Energy, presented by GAIN: Rift grows in GOP over climate change ... Greens celebrate Endangered Species Day

Date: May 18, 2018 at 12:39:42 PM PDT

To: b6 [redacted]@rangemagazine.com <mailto b6 [redacted] rangemagazine.com> >

Reply-To: Washington Examiner <news@washingtonexaminer.com <mailto:news@washingtonexaminer.com> >

Washington Examiner's Daily On Energy Newsletter View this as website <https://mediadc.us17.list-manage.com/track/click?u=00b18e7544dd3ec267591c592&id=15523cada5&e=3264bae676>

dod <http://central.washingtonexaminer.com/wex-doe/files/2018/05/original_doe-header.png>

SHARE: <https://mediadc.us17.list-manage.com/track/click?u=00b18e7544dd3ec267591c592&id=8140a77712&e=3264bae676> Share on Facebook <https://mediadc.us17.list-manage.com/track/click?u=00b18e7544dd3ec267591c592&id=5b85b2e23c&e=3264bae676> Share on Twitter <https://mediadc.us17.list-manage.com/track/click?u=00b18e7544dd3ec267591c592&id=8dbfa697aa&e=3264bae676> Share on Google+

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RIFT GROWS IN GOP OVER CLIMATE CHANGE: Republicans who support combating climate change were shaking their heads Friday after a “wild day” during which members of the GOP expressed divergent views on the subject.

“Thursday was a wild day that shows us that most GOP representatives’ views on climate science are informed more by their ideological commitments than empirical fact or careful study,” Joseph Majkut, director of climate policy at the Niskanen Center, a free-market think tank, told Josh.

Rock and a hard place: Early Thursday, Rep. Mo Brooks, R-Ala., said that rocks falling into the ocean are causing sea levels to rise, preaching climate denial during a hearing focused on technologies that can help address global warming.

Brooks, a Tea Party Republican, said rocks from the California coastline and the White Cliffs of Dover tumble into the sea every year, contributing to sea-level rise.

"Every time you have that soil or rock or whatever it is that is deposited into the seas, that forces the sea levels to rise, because now you have less space in those oceans, because the bottom is moving up," Brooks said from his perch on the Science, Space and Technology Committee.

Steve Valk, director of communications of the Citizens’ Climate Lobby, a group focused on inspiring Republicans to take climate action, called Brooks’ remark the “hand-slapping-forehead moment of the week.”

‘Put politics aside’: Later in the day, Rep. Carlos Curbelo, R-Fla, a moderate whose state is already feeling the effects of sea level rise, boasted in an enthusiastic press release that the Climate Solutions Caucus that he heads had added five new members, including three Republicans.

The new GOP entrants, Reps. Erik Paulsen of Minnesota, Peter Roskam of Illinois, and Tom MacArthur of New

Jersey, bring the climate caucus membership to 78, half of whom are Republicans, showing that Congress can “put politics aside” to combat climate change, Curbelo said.

‘Major way’: But politics surely affected the calculus of former House conservative lawmaker Jim Bridenstine of Oklahoma, who expressed denial of humans’ role in climate change before becoming the new administrator of NASA last month.

Now that he heads an agency that studies the changing climate, and doesn’t represent a conservative district in Congress, Bridenstine is expressing new views.

"I fully believe and know that the climate is changing. I also know that we, human beings, are contributing to it in a major way," Bridenstine told NASA employees at a town hall-style meeting Thursday.

Majkut and Valk hope the actions of Bridenstine and the Climate Solutions Caucus’ Republicans send a message to other conservatives.

Patience please: “Low information beliefs are malleable,” Majkut said. “Look what happened with Mr. Bridenstine. As soon as he started working with a bunch of experts down the hall, his rhetoric shifted substantially. I hope his leadership demonstrates that one can fully embrace climate science, or even think climate change is bad, without surrendering his membership in the Conservative movement.”

Added Valk: “Progress is being made. Patience will eventually be rewarded.”

FW: NASA website

From:	Happer, William EOP/NSC <b6 [redacted]>
To:	'j.morhard@nasa.gov' <j.morhard@nasa.gov>
Sent:	February 26, 2019 9:53:18 AM EST
Received:	February 26, 2019 9:53:21 AM EST

Dear James,

Not an agency record [redacted] thanks for the kind greeting from Jim Bridenstine.

Not an agency record [redacted]

Best wishes,

Will

--

Dr. William Happer

Deputy Assistant to the President

Senior Director for Emerging Technologies

National Security Council

[redacted]

From: William Happer <[redacted]>
Sent: Tuesday, February 26, 2019 6:54 AM
To: Happer, William EOP/NSC <[redacted]>
Subject: [EXTERNAL] Fw: NASA website

From: [redacted]
Sent: Tuesday, February 26, 2019 3:57 AM
To: William Happer
Cc: [redacted]
Subject: NASA website

26th February 2019

Dear Will

It's been a while since we last communicated and I'm contacting you with reference to the NASA website and its climate content for kids at: >https://climatekids.nasa.gov/menu/weather-and-climate/< <>https:/climatekids.nasa.gov/menu/weather-and-climate/<>

And the main NASA climate site at: >https://climate.nasa.gov/evidence/< <>https:/climate.nasa.gov/evidence/<>

In Australia, many primary school teachers (and secondary) use the NASA website to teach about climate change and most have very little science background so essentially the blind are leading the blind, trusting the accuracy of information on climate provided by NASA.

Much of the material on both sites are biased, emotive and without any evidence. There are statements such as: "Ninety-seven percent of climate scientists agree that climate-warming trends over the past century are very likely due to human activities, and most of the leading scientific organizations worldwide have issued public statements endorsing this position."

And: "The Maldives are vulnerable to sea level rise."

The site references the IPCC and Ben Santer as authorities, ignoring many facts that oppose the alarmism. I'm concerned that many children are being indoctrinated by this bad science.

I have emailed the Site Editor Holly Shaftel and Site Manager Randal Jackson putting forward my constructive criticism with evidence but received no reply. I have mailed a letter (yes - one with stamps!) to the NASA administration and received no reply.

Are you able to give me any email addresses for personnel at NASA who might do something about this misinformation that a trusting public will accept without question.

Many thanks and kind regards.

b6 [redacted]

b6 [redacted]

P.S. I hope global warming isn't bringing too much snow to your area.

Re: Feedback?

From: Thomas Wysmuller [redacted]
To: [redacted]
Cc: Doiron Hal <[redacted]
Sent: March 5, 2019 12:20:55 AM EST
Received: March 5, 2019 12:21:13 AM EST

The progress made by our whole NASA TRCS group - and its growing reputation for excellence - never ceases to amaze me!!!

[redacted]

PS a few bccs

On Mar 4, 2019, at 10:24 PM, [redacted] <mailto[redacted]> wrote:

Tom,

Thanks a lot for dropping your dime on Will's desk!

"By chance, Tom Wysmuller stopped by my office on Saturday,…"

I love it! You never cease to amaze me.

[redacted]

From: Hal Doiron [mailto [redacted]]
Sent: 4 March, 2019 12:23 PM
To: [redacted]
Cc [redacted] <mailto[redacted]> ; [redacted]
Subject: Fw: Feedback?

[redacted],

FYI. I took my shot at getting involved with the Trump Administration's review of climate science that Dr. Will Happer is heading up in his role as New Technology Adviser to John Bolton, the National Security Advisor.

Tom Wysmuller,

Thanks for suggesting Will Happer send me his paper for review. What have you learned about how he plans to conduct the internal Administration review of the Anthropogenic Global Warming (AGW) threat?

Hal

Harold H. Doiron, PhD
[redacted]

Home/Ofc: [redacted] Cell: [redacted]

----- Forwarded Message -----
From: Hal Doiron <[redacted] <mailto [redacted]> >
To: [redacted] <mailto [redacted]> <[redacted]
<mailto [redacted]> >
Cc: [redacted] <mailto[redacted]> [redacted] <mailto [redacted]> >;
[redacted] <mailto[redacted]> [redacted] <mailto[redacted] >
Sent: Monday, March 4, 2019 12:15:59 PM CST
Subject: Re: Feedback?

Will,

I am honored that you would want me to review your paper. I will get to it this week.

I am also very eager to get involved with the internal government review of climate science that newspaper reports indicate you are organizing. As you know, I have been leading a NASA retiree independent assessment of the Anthropogenic Global Warming (AGW) issue for the last 7 years. Our assessment of GHG climate sensitivity is completed and we believe Transient Cilmate Response is bounded to the high side by 1.3C and Equilibrium Climate Sensitivity is <1.6C. Our results are essentially the same as published by Lewis and Curry (2018) using similar data.

We derived a simple algebraic global mean surface temperature model from Conservation of Energy (Power in W/m^2) considerations and validated it with HadCRUT4 global temp data and AR5 atmospheric GHG and aerosol concentration history since 1850. Our analysis assumed the generally accepted reduction in IR flux leaving the atmosphere for doubling CO2 concentration was 3.71 W/m^2, and that surface temperature would adjust to compensate. We conservatively assumed that all observed HadCRUT4 global surface temperature increase since 1850 was due to rising atmospheric GHG and aerosol concentrations and none was due to a likely natural 1000 year warming cycle that fits the Roman Warm Period, Medieval Warm Period AND Little ice Age surface temperature variations, and that should peak out in about 2100.

The HadCRUT4 data and atmospheric GHG history allowed us to determine Transient Climate Response which was an undetermined constant in our simple algebraic model that related surface temperature to atmospheric GHG concentration. Our value for Transient Climate Response is < 1.3C including all climate feedbacks. The generally accepted 1.1C warming value for surface temperature increase without climate feedbacks due to doubling CO2 concentration (ie. due only to the 3.71 W/m^2 reduction in outgoing IR flux). This proves with data that climate feedbacks have at most, a small positive effect. When natural warming cycle effects in the temperature data are considered, climate feedbacks could be negative, or stabilizing. At any rate, there is no cause for climate alarm and we estimate <1C additional warming by 2100 (should be beneficial) due to burning all currently known world-wide reserves of coal, oil and natural gas.

Best regards,

Hal Doiron
Sent from Yahoo Mail on Android<https://go.onelink.me/107872968?pid=InProduct
<https://urldefense.proofpoint.com/v2/url?u=https-3A__go.onelink.me_107872968-3Fpid-3DInProduct-26c-3DGlobal-5FInternal-5FYGrowth-5FAndroidEmailSig-5F-5FAndroidUsers-26af-5Fwl-3Dym-26af-5Fsub1-3DInternal-26af-5Fsub2-3DGlobal-5FYGrowth-26af-5Fsub3-3DEmailSignature&d=DwMFaQ&c=ApwzowJNAKKw3xye91w7BE1XMRKi2LN9kiMk5Csz9Zk&r=C0aKhYUsT0IgrOLD-D1nNo4vZ8GBmPQV2uSrtXIuXYU&m=fKrfmIX7VEb3VFRi3vzgP1Dl2vqlGLYN0qqcfhZhFt4&s=xkOYMHioY1eaVvwjhw52F3c8XrbMFTPIwnoihBoWDnk&e=>
&c=Global_Internal_YGrowth_AndroidEmailSig__AndroidUsers&af_wl=ym&af_sub1=Internal&af_sub2=Global_YGrow

th&af_sub3=EmailSignature>

On Sun, Mar 3, 2019 at 8:28 PM, William Happer
[redacted] <mailto [redacted]> > wrote:
Dear Hal,

By chance, Tom Wysmuller stopped by my office on Saturday, and I showed him a copy of the attached draft paper that [redacted] and I hope to finish soon. Tom urged me to send you a copy, even without asking permission which I would normally do. If you have time to look it over and provide feedback on how to make it more useful to a wider readership, [redacted] and I would be very grateful.

We hope to publish the paper in a journal like Reviews of Modern Physics for readers who are not intimidated by integral equations or quantum mechanics. But we also hope that it will be useful to smart readers without a lot of mathematics background.

Key parts that require almost no math are Figs. 9-11, which show how little you change the infrared flux leaving the Earth if you double the concentrations of CO_2, N_2O or CH_4. Table 4 shows the correspondingly small temperature changes needed to restore thermal equilibrium if you double the concentrations.

We would be very pleased to get some feedback.

Best wishes,

Will

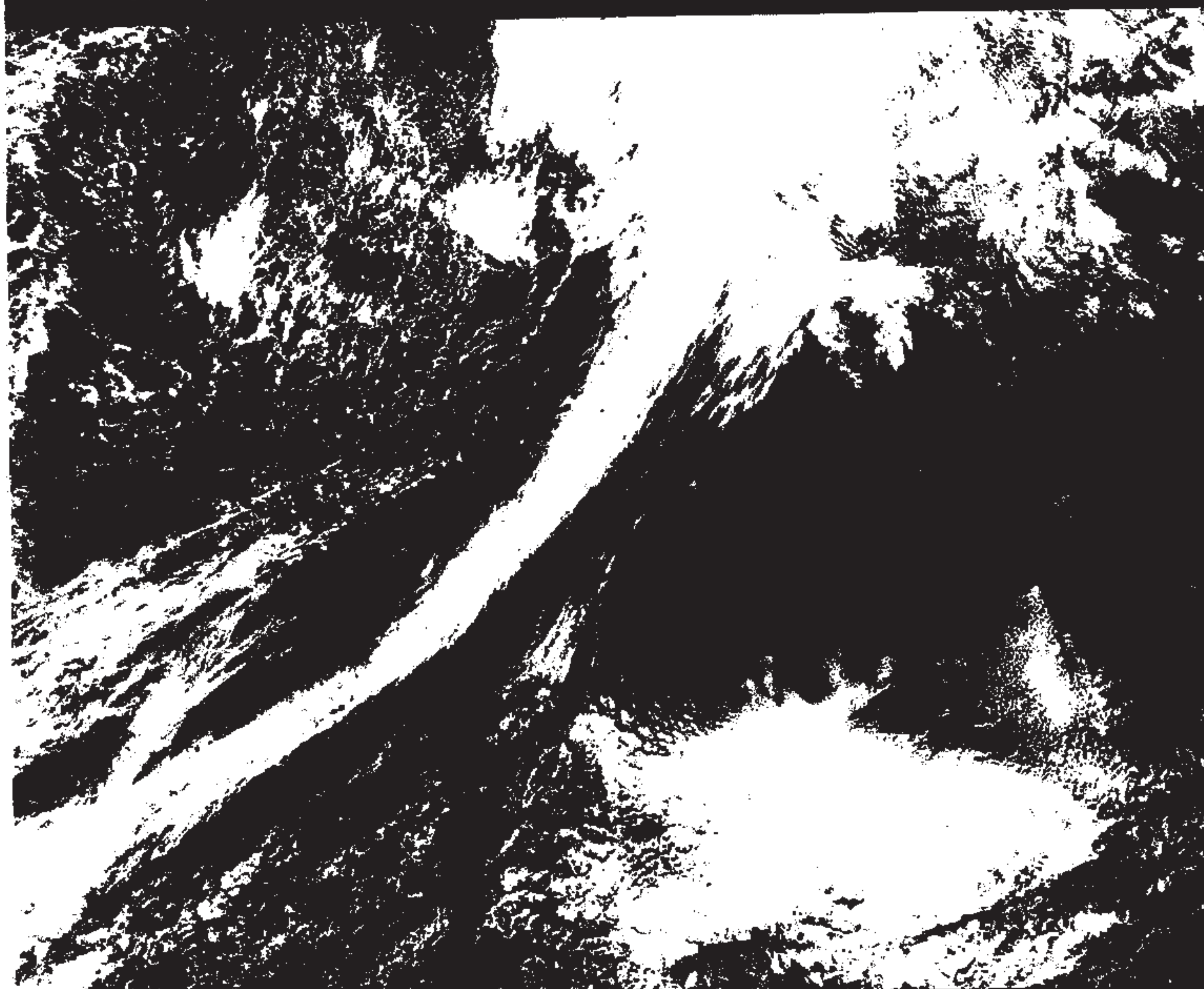
Deletion Page

10 pages of a non-agency record withheld per consultation with the NSC

Tab D

U.S. Global Change Research Program

CLIMATE SCIENCE SPECIAL REPORT



Executive Summary

Fourth National Climate Assessment | Volume I

Doc 10

On-line at science2017.globalchange.gov

First published 2017

Recommended Citation

Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, B. DeAngelo, S. Doherty, K. Hayhoe, R. Horton, J.P. Kossin, P.C. Taylor, A.M. Waple, and C.P. Weaver, 2017: *Executive Summary of the Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 26 pp.

Image Credit

Front Cover: Atmospheric rivers are relatively long, narrow regions in the atmosphere – like rivers in the sky – that transport most of the water vapor outside of the tropics. When an atmospheric river makes landfall, extreme precipitation and flooding can often result. The cover features a natural-color image of conditions over the northeastern Pacific on 20 February 2017, helping California and the American West emerge from a 5-year drought in stunning fashion. Some parts of California received nearly twice as much rain in a single deluge as normally falls in the preceding 5 months (October - February). The visualization was generated by Jesse Allen (NASA Earth Observatory) using data from the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) satellite.

CLIMATE SCIENCE SPECIAL REPORT

Executive Summary

Fourth National Climate Assessment | Volume I

U.S. Global Change Research Program

Doc 10

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Report Production

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About This Executive Summary

As a key part of the Fourth National Climate Assessment (NCA4), the U.S. Global Change Research Program (USGCRP) oversaw the production of this stand-alone report of the state of science relating to climate change and its physical impacts.

The Climate Science Special Report (CSSR) is designed to be an authoritative assessment of the science of climate change, with a focus on the United States, to serve as the foundation for efforts to assess climate-related risks and inform decision-making about responses. In accordance with this purpose, it does not include an assessment of literature on climate change mitigation, adaptation, economic valuation, or societal responses, nor does it include policy recommendations.

As Volume 1 of NCA4, CSSR serves several purposes, including providing 1) an updated and detailed analysis of the findings of how climate change is affecting weather and climate across the United States; 2) an executive summary and 15 chapters that provide the basis for the discussion of climate science found in the second volume of NCA4; and 3) foundational information and projections for climate change, including extremes, to improve "end-to-end" consistency in sectoral, regional, and resilience analyses within the second volume. CSSR integrates and evaluates the findings on climate science and discusses the uncertainties associated with these findings. It analyzes current trends in climate change, both human-induced and natural, and projects major trends to the end of this century. As an assessment and analysis of the science, CSSR provides important input to the development of other parts of NCA4, and their primary focus on the human welfare, societal, economic and environmental elements of climate change.

Much of the underlying report is written at a level more appropriate for a scientific audience, though the Executive Summary is intended to be accessible to a broader audience.

Report Development, Review, and Approval Process

The National Oceanic and Atmospheric Administration (NOAA) serves as the administrative lead agency for preparation of NCA4. The CSSR Federal Science Steering Committee (SSC)[1] has representatives from three agencies (NOAA, the National Aeronautics and Space Administration [NASA], and the Department of Energy [DOE]); USGCRP;[2] and three Coordinating Lead Authors, all of whom were Federal employees during development of this report. Following a public notice for author nominations in March 2016, the SSC selected the writing team, consisting of scientists representing Federal agencies, national laboratories, universities, and the private sector.

[1] The CSSR SSC was charged with overseeing the development and production of the report. SSC membership was open to all USGCRP agencies.
[2] The USGCRP is made up of 13 Federal departments and agencies that carry out research and support the Nation's response to global change. The USGCRP is overseen by the Subcommittee on Global Change Research (SGCR) of the National Science and Technology Council's Committee on Environment, Natural Resources, and Sustainability (CENRS), which in turn is overseen by the White House Office of Science and Technology Policy (OSTP). The agencies within USGCRP are the Department of Agriculture, the Department of Commerce (NOAA), the Department of Defense, the Department of Energy, the Department of Health and Human Services, the Department of the Interior, the Department of State, the Department of Transportation, the Environmental Protection Agency, the National Aeronautics and Space Administration, the National Science Foundation, the Smithsonian Institution, and the U.S. Agency for International Development.

The first Lead Author Meeting was held in Washington, DC, in April 2016, to refine the outline contained in the SSC-endorsed prospectus and to make writing assignments. Over the course of 18 months before final publication, seven CSSR drafts were generated, with each successive iteration—from zero- to sixth-order drafts—undergoing additional expert review, by the SSC (multiple times), the USGCRP agencies (multiple times), the general public, and the National Academies of Sciences, Engineering, and Medicine (NAS).[3] The final review and sign-off of CSSR by the USGCRP agencies occurred in August 2017 under the auspices of the Office of Science and Technology Policy (OSTP); OSTP is responsible for the Federal clearance process prior to the final report production and public release.

The Sustained National Climate Assessment

The Climate Science Special Report has been developed as part of the USGCRP's sustained National Climate Assessment process. This process facilitates continuous and transparent participation of scientists and stakeholders across regions and sectors, enabling new information and insights to be assessed as they emerge. The Climate Science Special Report conducted a comprehensive assessment of the science underlying the changes occurring in Earth's climate system, with a special focus on the United States.

Sources Used in this Report

The findings in this report are based on a large body of scientific, peer-reviewed research, as well as a number of other publicly available sources, including well-established and carefully evaluated observational and modeling datasets. The team of authors carefully reviewed these sources to ensure a reliable assessment of the state of scientific understanding. Each source of information was determined to meet the four parts of the quality assurance guidance provided to authors (following the approach from the Third National Climate Assessment): 1) utility, 2) transparency and traceability, 3) objectivity, and 4) integrity and security. Report authors assessed and synthesized information from peer-reviewed journal articles, technical reports produced by Federal agencies, scientific assessments (such as the rigorously-reviewed international assessments from the Intergovernmental Panel on Climate Change), reports of the NAS and its associated National Research Council, and various regional climate impact assessments, conference proceedings, and government statistics (such as population census and energy usage).

[3] Author responses to comments submitted as part of the Public Comment Period and a USGCRP response to the review conducted by NAS can be found on <science2017.globalchange.gov/downloads>.

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Treatment of Uncertainties: Likelihoods, Confidence, and Risk Framing

Throughout this report's assessment of the scientific understanding of climate change, the authors have assessed to the fullest extent possible the state-of-the-art understanding of the science resulting from the information in the scientific literature to arrive at conclusions referred to as Key Findings. The approach used to represent the extent of understanding represented in the Key Findings is done through two metrics:

> **Confidence** in the validity of a finding based on the type, amount, quality, strength, and consistency of evidence (such as mechanistic understanding, theory, data, models, and expert judgment); the skill, range, and consistency of model projections; and the degree of agreement within the body of literature.
>
> **Likelihood**, or probability of an effect or impact occurring, is based on measures of uncertainty expressed probabilistically (based on the degree of understanding or knowledge, e.g., resulting from evaluating statistical analyses of observations or model results or on expert judgment).

Assessments of confidence in the Key Findings are based on the expert judgment of the author team. Authors provide supporting evidence for each of the chapter's Key Findings in the Traceable Accounts. Confidence is expressed qualitatively and ranges from low confidence (inconclusive evidence or disagreement among experts) to very high confidence (strong evidence and high consensus) (see table on inside of back cover for the full range). Confidence should not be interpreted probabilistically, as it is distinct from statistical likelihood.

In this report, likelihood is the chance of occurrence of an effect or impact based on measures of uncertainty expressed probabilistically (based on statistical analysis of observations or model results or on expert judgment). The authors used expert judgment based on the synthesis of the literature assessed to arrive at an estimation of the likelihood that a particular observed effect was related to human contributions to climate change or that a particular impact will occur within the range of possible outcomes. Model uncertainty is an important contributor to uncertainty in climate projections, and includes, but is not restricted to, the uncertainties introduced by errors in the model's representation of the physical and bio-geochemical processes affecting the climate system as well as in the model's response to external forcing.

Where it is considered justified to report the likelihood of particular impacts within the range of possible outcomes, this report takes a plain-language approach to expressing the expert judgment of the chapter team, based on the best available evidence. For example, an outcome termed "likely" has at least a 66% chance of occurring (a likelihood greater than about 2 of 3 chances); an outcome termed "very likely," at least a 90% chance (more than 9 out of 10 chances).

Highlights of the U.S. Global Change Research Program Climate Science Special Report

The climate of the United States is strongly connected to the changing global climate. The statements below highlight past, current, and projected climate changes for the United States and the globe.

Global annually averaged surface air temperature has increased by about 1.8°F (1.0°C) over the last 115 years (1901–2016). **This period is now the warmest in the history of modern civilization.** The last few years have also seen record-breaking, climate-related weather extremes, and the last three years have been the warmest years on record for the globe. These trends are expected to continue over climate timescales.

This assessment concludes, based on extensive evidence, that it is extremely likely that **human activities, especially emissions of greenhouse gases, are the dominant cause of the observed warming since the mid-20th century.** For the warming over the last century, there is no convincing alternative explanation supported by the extent of the observational evidence.

In addition to warming, many other aspects of global climate are changing, primarily in response to human activities. **Thousands of studies conducted by researchers around the world have documented changes in surface, atmospheric, and oceanic temperatures; melting glaciers; diminishing snow cover; shrinking sea ice; rising sea levels; ocean acidification; and increasing atmospheric water vapor.**

For example, **global average sea level has risen by about 7–8 inches** since 1900, with almost half (about 3 inches) of that rise occurring since 1993. Human-caused climate change has made a substantial contribution to this rise since 1900, contributing to a rate of rise that is greater than during any preceding century in at least 2,800 years. Global sea level rise has already affected the United States; **the incidence of daily tidal flooding is accelerating in more than 25 Atlantic and Gulf Coast cities.**

Global average sea levels are expected to continue to rise—by at least several inches in the next 15 years and by 1–4 feet by 2100. A rise of as much as 8 feet by 2100 cannot be ruled out. Sea level rise will be higher than the global average on the East and Gulf Coasts of the United States.

Changes in the characteristics of extreme events are particularly important for human safety, infrastructure, agriculture, water quality and quantity, and natural ecosystems. **Heavy rainfall is increasing in intensity and frequency across the United States and globally and is expected to continue to increase.** The largest observed changes in the United States have occurred in the Northeast.

Heatwaves have become more frequent in the United States since the 1960s, while extreme cold temperatures and cold waves are less frequent. Recent record-setting hot years are projected to become common in the near future for the United States, as annual average temperatures continue to rise. Annual average temperature over the contiguous United States has increased by 1.8°F (1.0°C) for the period 1901–2016; **over the next few decades (2021–2050), annual average temperatures are expected to rise by about 2.5°F for the United States, relative to the recent past (average from 1976–2005), under all plausible future climate scenarios.**

The incidence of large forest fires in the western United States and Alaska has increased since the early 1980s and is projected to further increase in those regions as the climate changes, with profound changes to regional ecosystems.

Annual trends toward earlier spring melt and reduced snowpack are already affecting water resources in the western United States and these trends are expected to continue. Under higher scenarios, and assuming no change to current water resources management, **chronic, long-duration hydrological drought is increasingly possible before the end of this century.**

The magnitude of climate change beyond the next few decades will depend primarily on the amount of greenhouse gases (especially carbon dioxide) emitted globally. Without major reductions in emissions, the increase in annual average global temperature relative to preindustrial times could reach 9°F (5°C) or more by the end of this century. **With significant reductions in emissions, the increase in annual average global temperature could be limited to 3.6°F (2°C) or less.**

The global atmospheric carbon dioxide (CO_2) concentration has now passed 400 parts per million (ppm), a level that last occurred about 3 million years ago, when both global average temperature and sea level were significantly higher than today. Continued growth in CO_2 emissions over this century and beyond would lead to an atmospheric concentration not experienced in tens to hundreds of millions of years. There is broad consensus that the further and the faster the Earth system is pushed towards warming, the greater the risk of unanticipated changes and impacts, some of which are potentially large and irreversible.

The observed increase in carbon emissions over the past 15–20 years has been consistent with higher emissions pathways. **In 2014 and 2015, emission growth rates slowed as economic growth became less carbon-intensive.** Even if this slowing trend continues, however, it is not yet at a rate that would limit global average temperature change to well below 3.6°F (2°C) above preindustrial levels.

Recommended Citation for the Full Report

USGCRP, 2017: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp.

Executive Summary

Introduction

New observations and new research have increased our understanding of past, current, and future climate change since the Third U.S. National Climate Assessment (NCA3) was published in May 2014. This Climate Science Special Report (CSSR) is designed to capture that new information and build on the existing body of science in order to summarize the current state of knowledge and provide the scientific foundation for the Fourth National Climate Assessment (NCA4).

Since NCA3, stronger evidence has emerged for continuing, rapid, human-caused warming of the global atmosphere and ocean. This report concludes that "it is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century. For the warming over the last century, there is no convincing alternative explanation supported by the extent of the observational evidence."

The last few years have also seen record-breaking, climate-related weather extremes, the three warmest years on record for the globe, and continued decline in arctic sea ice. These trends are expected to continue in the future over climate (multidecadal) timescales. Significant advances have also been made in our understanding of extreme weather events and how they relate to increasing global temperatures and associated climate changes. Since 1980, the cost of extreme events for the United States has exceeded $1.1 trillion; therefore, better understanding of the frequency and severity of these events in the context of a changing climate is warranted.

Periodically taking stock of the current state of knowledge about climate change and putting new weather extremes, changes in sea ice, increases in ocean temperatures, and ocean acidification into context ensures that rigorous, scientifically-based information is available to inform dialogue and decisions at every level. This climate science report serves as the climate science foundation of the NCA4 and is generally intended for those who have a technical background in climate science. In this Executive Summary, gray boxes present highlights of the main report. These are followed by related points and selected figures providing more scientific details. The summary material on each topic presents the most salient points of chapter findings and therefore represents only a subset of the report's content. For more details, the reader is referred to the individual chapters. This report discusses climate trends and findings at several scales: global, nationwide for the United States, and for ten specific U.S. regions (shown in Figure 1 in the Guide to the Report). A statement of scientific confidence also follows each point in the Executive Summary. The confidence scale is described in the Guide to the Report. At the end of the Executive Summary and in Chapter 1: Our Globally Changing Climate, there is also a summary box highlighting the most notable advances and topics since NCA3 and since the 2013 Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report.

Global and U.S. Temperatures Continue to Rise

Long-term temperature observations are among the most consistent and widespread evidence of a warming planet. Temperature (and, above all, its local averages and extremes) affects agricultural productivity, energy use, human health, water resources, infrastructure, natural ecosystems, and many other essential aspects of society and the natural environment. Recent data add to the weight of evidence for rapid global-scale warming, the dominance of human causes, and the expected continuation of increasing temperatures, including more record-setting extremes. (Ch. 1)

Changes in Observed and Projected Global Temperature

The global, long-term, and unambiguous warming trend has continued during recent years. Since the last National Climate Assessment was published, 2014 became the warmest year on record globally; 2015 surpassed 2014 by a wide margin; and 2016 surpassed 2015. Sixteen of the warmest years on record for the globe occurred in the last 17 years (1998 was the exception). (Ch. 1; Fig. ES.1)

- Global annual average temperature (as calculated from instrumental records over both land and oceans) has increased by more than 1.2°F (0.65°C) for the period 1986–2016 relative to 1901–1960; the linear regression change over the entire period from 1901–2016 is 1.8°F (1.0°C) (*very high confidence*; Fig. ES.1). Longer-term climate records over past centuries and millennia indicate that average temperatures in recent decades over much of the world have been much higher, and have risen faster during this time period than at any time in the past 1,700 years or more, the time period for which the global distribution of surface temperatures can be reconstructed (*high confidence*). (Ch. 1)

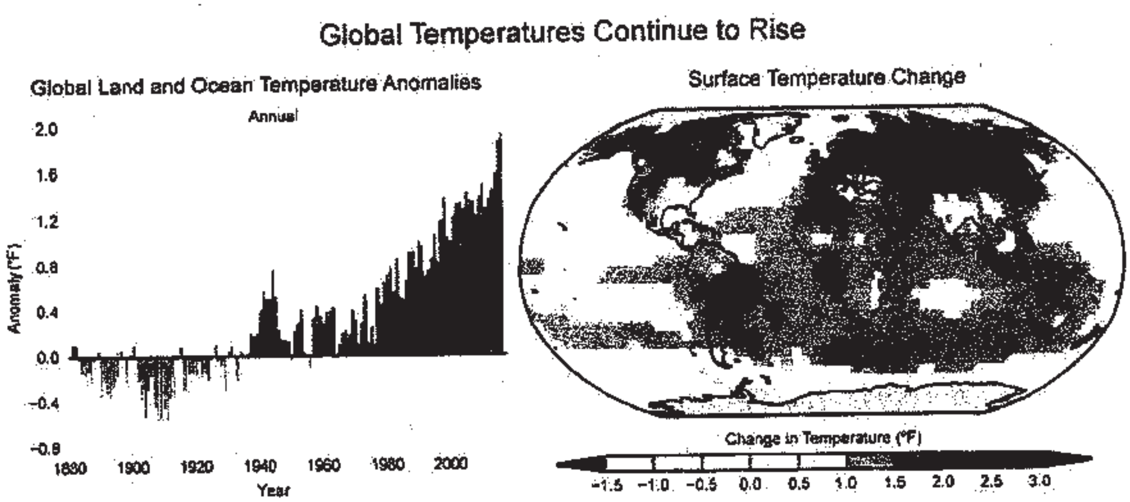

Figure ES.1: (left) Global annual average temperature has increased by more than 1.2°F (0.7°C) for the period 1986–2016 relative to 1901–1960. Red bars show temperatures that were above the 1901–1960 average, and blue bars indicate temperatures below the average. (right) Surface temperature change (in °F) for the period 1986–2016 relative to 1901–1960. Gray indicates missing data. *From Figures 1.2 and 1.3 in Chapter 1.*

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- Many lines of evidence demonstrate that it is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century. Over the last century, there are no convincing alternative explanations supported by the extent of the observational evidence. Solar output changes and internal natural variability can only contribute marginally to the observed changes in climate over the last century, and there is no convincing evidence for natural cycles in the observational record that could explain the observed changes in climate. (*Very high confidence*) (Ch. 1)

- The *likely* range of the human contribution to the global mean temperature increase over the period 1951–2010 is 1.1° to 1.4°F (0.6° to 0.8°C), and the central estimate of the observed warming of 1.2°F (0.65°C) lies within this range (*high confidence*). This translates to a *likely* human contribution of 92%–123% of the observed 1951–2010 change. The *likely* contributions of natural forcing and internal variability to global temperature change over that period are minor (*high confidence*). (Ch. 3; Fig. ES.2)

- Natural variability, including El Niño events and other recurring patterns of ocean–atmosphere interactions, impact temperature and precipitation, especially regionally, over timescales of months to years. The global influence of natural variability, however, is limited to a small fraction of observed climate trends over decades. (*Very high confidence*) (Ch. 1)

Human Activities Are the Primary Driver of Recent Global Temperature Rise

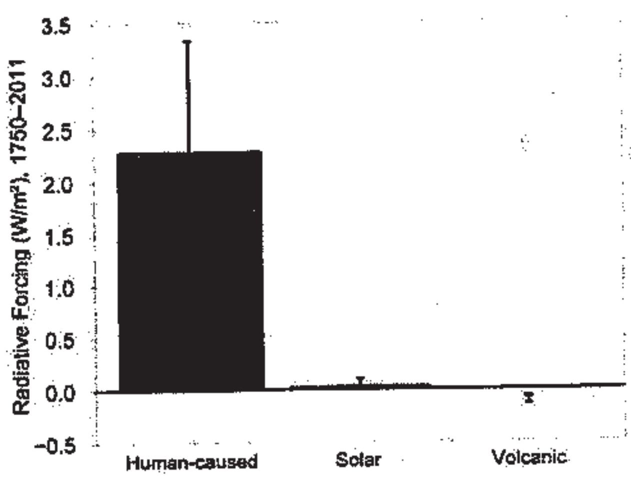

Figure ES.2: Global annual average radiative forcing change from 1750 to 2011 due to human activities, changes in total solar irradiance, and volcanic emissions. Black bars indicate the uncertainty in each. Radiative forcing is a measure of the influence a factor (such as greenhouse gas emissions) has in changing the global balance of incoming and outgoing energy. Radiative forcings greater than zero (positive forcings) produce climate warming; forcings less than zero (negative forcings) produce climate cooling. Over this time period, solar forcing has oscillated on approximately an 11-year cycle between −0.11 and +0.19 W/m². Radiative forcing due to volcanic emissions is always negative (cooling) and can be very large immediately following significant eruptions but is short-lived. Over the industrial era, the largest volcanic forcing followed the eruption of Mt. Tambora in 1815 (−11.6 W/m²). This forcing declined to −4.5 W/m² in 1816, and to near-zero by 1820. Forcing due to human activities, in contrast, has becoming increasingly positive (warming) since about 1870, and has grown at an accelerated rate since about 1970. There are also natural variations in temperature and other climate variables which operate on annual to decadal timescales. This natural variability contributes very little to climate trends over decades and longer. *Simplified from Figure 2.6 in Chapter 2. See Chapter 2 for more details.*

- Global climate is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades will depend primarily on the amount of greenhouse (heat-trapping) gases emitted globally and on the remaining uncertainty in the sensitivity of Earth's climate to those emissions (*very high confidence*). With significant reductions in the emissions of greenhouse gases, the global annually averaged temperature rise could be limited to 3.6°F (2°C) or less. Without major reductions in these emissions, the increase in annual average global temperatures relative to preindustrial times could reach 9°F (5°C) or more by the end of this century. (Ch. 1; Fig. ES.3)

- If greenhouse gas concentrations were stabilized at their current level, existing concentrations would commit the world to at least an additional 1.1°F (0.6°C) of warming over this century relative to the last few decades (*high confidence* in continued warming, *medium confidence* in amount of warming. (Ch. 4)

Scenarios Used in this Assessment

Projections of future climate conditions use a range of plausible future scenarios. Consistent with previous practice, this assessment relies on scenarios generated for the Intergovernmental Panel on Climate Change (IPCC). The IPCC completed its last assessment in 2013–2014, and its projections were based on updated scenarios, namely four "representative concentration pathways" (RCPs). The RCP scenarios are numbered according to changes in radiative forcing in 2100 relative to preindustrial conditions: +2.6, +4.5, +6.0 and +8.5 watts per square meter (W/m²). Radiative forcing is a measure of the influence a factor (such as greenhouse gas emissions) has in changing the global balance of incoming and outgoing energy. Absorption by greenhouse gases (GHGs) of infrared energy radiated from the surface leads to warming of the surface and atmosphere. Though multiple emissions pathways could lead to the same 2100 radiative forcing value, an associated pathway of CO_2 and other human-caused emissions of greenhouse gases, aerosols, and air pollutants has been selected for each RCP. RCP8.5 implies a future with continued high emissions growth, whereas the other RCPs represent different pathways of mitigating emissions. Figure ES.3 shows these emissions pathways and the corresponding projected changes in global temperature.

Greater Emissions Lead to Significantly More Warming

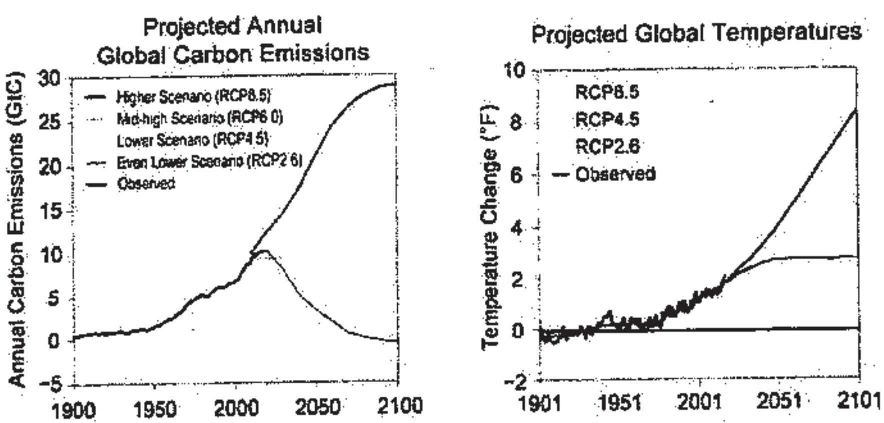

Figure ES.3: The two panels above show annual historical and a range of plausible future carbon emissions in units of gigatons of carbon (GtC) per year (left) and the historical observed and future temperature change that would result for a range of future scenarios relative to the 1901–1960 average, based on the central estimate (lines) and a range (shaded areas, two standard deviations) as simulated by the full suite of CMIP5 global climate models (right). By 2081–2100, the projected range in global mean temperature change is 1.1°–4.3°F under the even lower scenario (RCP2.6; 0.6°–2.4°C, green), 2.4°–5.9°F under the lower scenario (RCP4.5; 1.3°–3.3°C, blue), 3.0°–6.8°F under the mid-high scenario (RCP6.0; 1.6°–3.8°C, not shown) and 5.0°–10.2°F under the higher scenario (RCP8.5; 2.8°–5.7°C, orange). See the main report for more details on these scenarios and implications. *Based on Figure 4.1 in Chapter 4.*

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Changes in Observed and Projected U.S. Temperature

Annual average temperature over the contiguous United States has increased by 1.8°F (1.0°C) for the period 1901–2016 and is projected to continue to rise. (*Very high confidence*). (Ch. 6; Fig. ES.4)

- Annual average temperature over the contiguous United States has increased by 1.2°F (0.7°C) for the period 1986–2016 relative to 1901–1960 and by 1.8°F (1.0°C) based on a linear regression for the period 1901–2016 (*very high confidence*). Surface and satellite data are consistent in their depiction of rapid warming since 1979 (*high confidence*). Paleo-temperature evidence shows that recent decades are the warmest of the past 1,500 years (*medium confidence*). (Ch. 6)

- Annual average temperature over the contiguous United States is projected to rise (*very high confidence*). Increases of about 2.5°F (1.4°C) are projected for the period 2021–2050 relative to the average from 1976–2005 in all RCP scenarios, implying recent record-setting years may be "common" in the next few decades (*high confidence*). Much larger rises are projected by late century (2071–2100): 2.8°–7.3°F (1.6°–4.1°C) in a lower scenario (RCP4.5) and 5.8°–11.9°F (3.2°–6.6°C) in a higher scenario (RCP8.5) (*high confidence*). (Ch. 6; Fig. ES.4)

- In the United States, the urban heat island effect results in daytime temperatures 0.9°–7.2°F (0.5°–4.0°C) higher and nighttime temperatures 1.8°–4.5°F (1.0°–2.5°C) higher in urban areas than in rural areas, with larger temperature differences in humid regions (primarily in the eastern United States) and in cities with larger and denser populations. The urban heat island effect will strengthen in the future as the structure and spatial extent as well as population density of urban areas change and grow (*high confidence*). (Ch. 10)

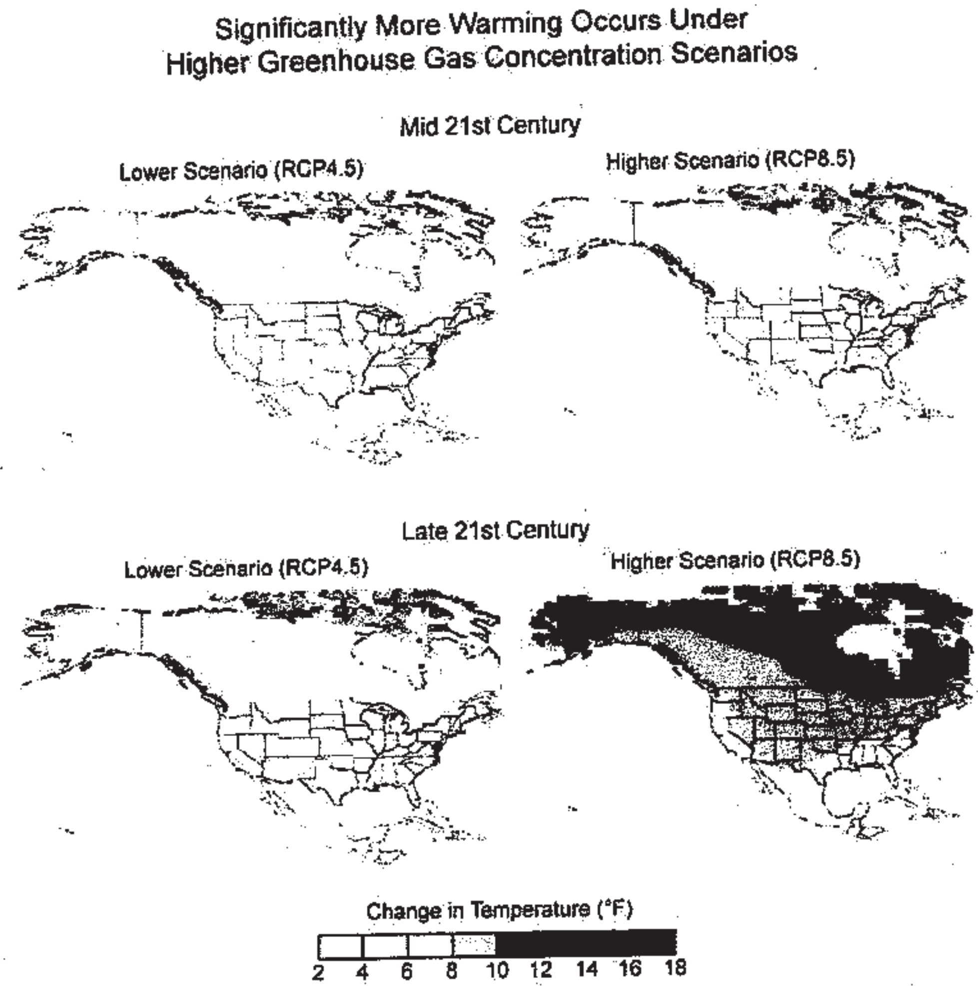

Figure ES.4: These maps show the projected changes in annual average temperatures for mid- and late-21st century for two future pathways. Changes are the differences between the average projected temperatures for mid-century (2036–2065; top), and late-century (2070–2099; bottom), and those observed for the near-present (1976–2005). *See Figure 6.7 in Chapter 6 for more details.*

Many Temperature and Precipitation Extremes Are Becoming More Common

Temperature and precipitation extremes can affect water quality and availability, agricultural productivity, human health, vital infrastructure, iconic ecosystems and species, and the likelihood of disasters. Some extremes have already become more frequent, intense, or of longer duration, and many extremes are expected to continue to increase or worsen, presenting substantial challenges for built, agricultural, and natural systems. Some storm types such as hurricanes, tornadoes, and winter storms are also exhibiting changes that have been linked to climate change, although the current state of the science does not yet permit detailed understanding.

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Observed Changes in Extremes

There have been marked changes in temperature extremes across the contiguous United States. The number of high temperature records set in the past two decades far exceeds the number of low temperature records. (*Very high confidence*) (Ch. 6, Fig. ES.5)

- The frequency of cold waves has decreased since the early 1900s, and the frequency of heat waves has increased since the mid-1960s (the Dust Bowl era of the 1930s remains the peak period for extreme heat in the United States). (*Very high confidence*). (Ch. 6)
- The frequency and intensity of extreme heat and heavy precipitation events are increasing in most continental regions of the world (*very high confidence*). These trends are consistent with expected physical responses to a warming climate. Climate model studies are also consistent with these trends, although models tend to underestimate the observed trends, especially for the increase in extreme precipitation events (*very high confidence* for temperature, *high confidence* for extreme precipitation). (Ch. 1)

Record Warm Daily Temperatures Are Occurring More Often

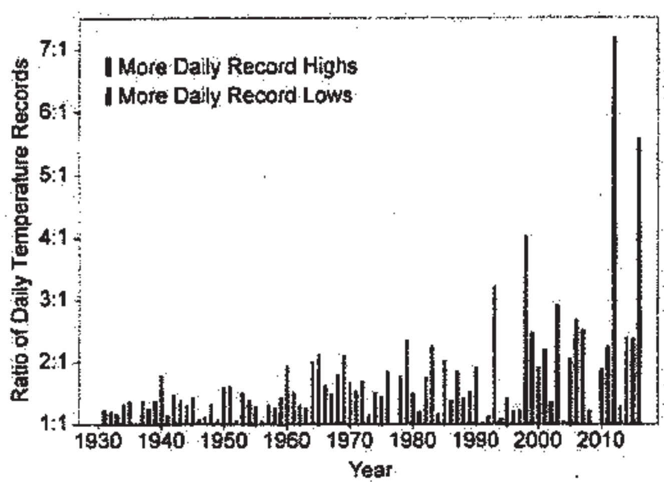

Figure ES.5: Observed changes in the occurrence of record-setting daily temperatures in the contiguous United States. Red bars indicate a year with more daily record highs than daily record lows, while blue bars indicate a year with more record lows than highs. The height of the bar indicates the ratio of record highs to lows (red) or of record lows to highs (blue). For example, a ratio of 2:1 for a blue bar means that there were twice as many record daily lows as daily record highs that year. (Figure source: NOAA/NCEI). *From Figure 6.5 in Chapter 6.*

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Heavy precipitation events in most parts of the United States have increased in both intensity and frequency since 1901 (*high confidence*). There are important regional differences in trends, with the largest increases occurring in the northeastern United States (*high confidence*). (Ch. 7; Fig. ES.6)

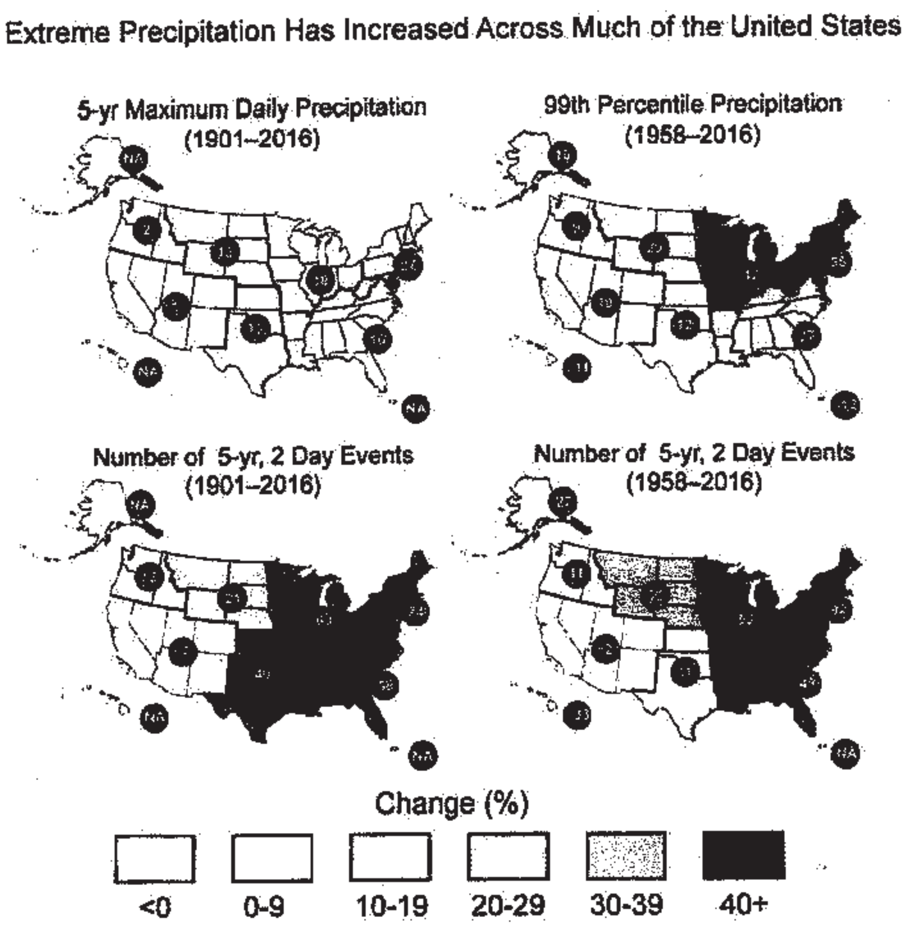

Figure ES.6: These maps show the percentage change in several metrics of extreme precipitation by NCA4 region, including (upper left) the maximum daily precipitation in consecutive 5-year periods; (upper right) the amount of precipitation falling in daily events that exceed the 99th percentile of all non-zero precipitation days (top 1% of all daily precipitation events); (lower left) the number of 2-day events with a precipitation total exceeding the largest 2-day amount that is expected to occur, on average, only once every 5 years, as calculated over 1901–2016; and (lower right) the number of 2-day events with a precipitation total exceeding the largest 2-day amount that is expected to occur, on average, only once every 5 years, as calculated over 1958–2016. The number in each black circle is the percent change over the entire period, either 1901–2016 or 1958–2016. Note that Alaska and Hawai'i are not included in the 1901–2016 maps owing to a lack of observations in the earlier part of the 20th century. *(Figure source: CICS-NC / NOAA NCEI). Based on figure 7.4 in Chapter 7.*

- Recent droughts and associated heat waves have reached record intensity in some regions of the United States; however, by geographical scale and duration, the Dust Bowl era of the 1930s remains the benchmark drought and extreme heat event in the historical record. (*Very high confidence*) (Ch. 8)

- Northern Hemisphere spring snow cover extent, North America maximum snow depth, snow water equivalent in the western United States, and extreme snowfall years in the southern and western United States have all declined, while extreme snowfall years in parts of the northern United States have increased. (*Medium confidence*). (Ch. 7)

- There has been a trend toward earlier snowmelt and a decrease in snowstorm frequency on the southern margins of climatologically snowy areas (*medium confidence*). Winter storm tracks have shifted northward since 1950 over the Northern Hemisphere (*medium confidence*). Potential linkages between the frequency and intensity of severe winter storms in the United States and accelerated warming in the Arctic have been postulated, but they are complex, and, to some extent, contested, and confidence in the connection is currently *low*. (Ch. 9)

- Tornado activity in the United States has become more variable, particularly over the 2000s, with a decrease in the number of days per year with tornadoes and an increase in the number of tornadoes on these days (*medium confidence*). Confidence in past trends for hail and severe thunderstorm winds, however, is *low* (Ch. 9)

Projected Changes in Extremes

- The frequency and intensity of extreme high temperature events are *virtually certain* to increase in the future as global temperature increases (*high confidence*). Extreme precipitation events will *very likely* continue to increase in frequency and intensity throughout most of the world (*high confidence*). Observed and projected trends for some other types of extreme events, such as floods, droughts, and severe storms, have more variable regional characteristics. (Ch. 1)

Extreme temperatures in the contiguous United States are projected to increase even more than average temperatures (*very high confidence*). (Ch. 6)

- Both extremely cold days and extremely warm days are expected to become warmer. Cold waves are predicted to become less intense while heat waves will become more intense. The number of days below freezing is projected to decline while the number above 90°F will rise. (*Very high confidence*) (Ch. 6)

- The frequency and intensity of heavy precipitation events in the United States are projected to continue to increase over the 21st century (*high confidence*). There are, however, important regional and seasonal differences in projected changes in total precipitation: the northern United States, including Alaska, is projected to receive more precipitation in the winter and spring, and parts of the southwestern United States are projected to receive less precipitation in the winter and spring (*medium confidence*). (Ch. 7)

- The frequency and severity of landfalling "atmospheric rivers" on the U.S. West Coast (narrow streams of moisture that account for 30%–40% of the typical snowpack and annual precipitation in the region and are associated with severe flooding events) will increase as a result of increasing evaporation and resulting higher atmospheric water vapor that occurs with increasing temperature. (*Medium confidence*) (Ch. 9)

- Projections indicate large declines in snowpack in the western United States and shifts to more precipitation falling as rain than snow in the cold season in many parts of the central and eastern United States (*high confidence*). (Ch. 7)

- Substantial reductions in western U.S. winter and spring snowpack are projected as the climate warms. Earlier spring melt and reduced snow water equivalent have been formally attributed to human-induced warming (*high confidence*) and will *very likely* be exacerbated as the climate continues to warm (*very high confidence*). Under higher scenarios, and assuming no change to current water resources management, chronic, long-duration hydrological drought is increasingly possible by the end of this century (*very high confidence*). (Ch. 8)

Future decreases in surface soil moisture from human activities over most of the United States are *likely* as the climate warms under the higher scenarios. (*Medium confidence*) (Ch. 8)

- The human effect on recent major U.S. droughts is complicated. Little evidence is found for a human influence on observed precipitation deficits, but much evidence is found for a human influence on surface soil moisture deficits due to increased evapotranspiration caused by higher temperatures. (*High confidence*) (Ch. 8)

- The incidence of large forest fires in the western United States and Alaska has increased since the early 1980s (*high confidence*) and is projected to further increase in those regions as the climate warms, with profound changes to certain ecosystems (*medium confidence*). (Ch. 8)

- Both physics and numerical modeling simulations generally indicate an increase in tropical cyclone intensity in a warmer world, and the models generally show an increase in the number of very intense tropical cyclones. For Atlantic and eastern North Pacific hurricanes and western North Pacific typhoons, increases are projected in precipitation rates (*high confidence*) and intensity (*medium confidence*). The frequency of the most intense of these storms is projected to increase in the Atlantic and western North Pacific (*low confidence*) and in the eastern North Pacific (*medium confidence*). (Ch. 9)

Box ES.1: The Connected Climate System: Distant Changes Affect the United States

Weather conditions and the ways they vary across regions and over the course of the year are influenced, in the United States as elsewhere, by a range of factors, including local conditions (such as topography and urban heat islands), global trends (such as human-caused warming), and global and regional circulation patterns, including cyclical and chaotic patterns of natural variability within the climate system. For example, during an El Niño year, winters across the southwestern United States are typically wetter than average, and global temperatures are higher than average. During a La Niña year, conditions across the southwestern United States are typically dry, and there tends to be a lowering of global temperatures (Fig. ES.7).

El Niño is not the only repeating pattern of natural variability in the climate system. Other important patterns include the North Atlantic Oscillation (NAO)/Northern Annular Mode (NAM), which particularly affects conditions on the U.S. East Coast, and the North Pacific Oscillation (NPO) and Pacific North American Pattern (PNA), which especially affect conditions in Alaska and the U.S. West Coast. These patterns are closely linked to other atmospheric circulation phenomena like the position of the jet streams. Changes in the occurrence of these patterns or their properties have contributed to recent U.S. temperature and precipitation trends (*medium confidence*) although *confidence is low* regarding the size of the role of human activities in these changes. (Ch. 5)

Understanding the full scope of human impacts on climate requires a global focus because of the interconnected nature of the climate system. For example, the climate of the Arctic and the climate of the continental United States are connected through atmospheric circulation patterns. While the Arctic may seem remote to most Americans, the climatic effects of perturbations to arctic sea ice, land ice, surface temperature, snow cover, and permafrost affect the amount of warming, sea level change, carbon cycle impacts, and potentially even weather patterns in the lower 48 states. The Arctic is warming at a rate approximately twice as fast as the global average and, if it continues to warm at the same rate, Septembers will be nearly ice-free in the Arctic Ocean sometime between now and the 2040s (see Fig. ES.10). The important influence of arctic climate change on Alaska is apparent; the influence of arctic changes on U.S. weather over the coming decades remains an open question with the potential for significant impact. (Ch. 11)

Changes in the Tropics can also impact the rest of the globe, including the United States. There is growing evidence that the Tropics have expanded poleward by about 70 to 200 miles in each hemisphere over the period 1979–2009, with an accompanying shift of the subtropical dry zones, midlatitude jets, and storm tracks (*medium to high confidence*). Human activities have played a role in the change (*medium confidence*), although confidence is presently low regarding the magnitude of the human contribution relative to natural variability (Ch. 5).

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Box ES.1 (*continued*)

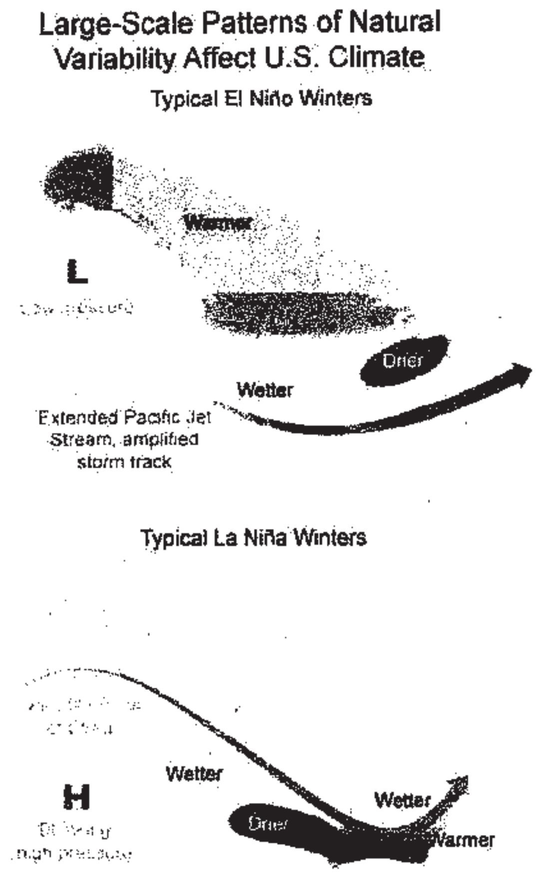

Figure ES.7: This figure illustrates the typical January–March weather anomalies and atmospheric circulation during moderate to strong (top) El Niño and (bottom) La Niña. These influences over the United States often occur most strongly during the cold season. *From Figure 5.2 in Chapter 5.*

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Oceans Are Rising, Warming, and Becoming More Acidic

Oceans occupy two-thirds of the planet's surface and host unique ecosystems and species, including those important for global commercial and subsistence fishing. Understanding climate impacts on the ocean and the ocean's feedbacks to the climate system is critical for a comprehensive understanding of current and future changes in climate.

Global Ocean Heat

The world's oceans have absorbed about 93% of the excess heat caused by greenhouse gas warming since the mid-20th century, making them warmer and altering global and regional climate feedbacks. (*Very high confidence*) (Ch. 13)

- Ocean heat content has increased at all depths since the 1960s and surface waters have warmed by about 1.3° ± 0.1°F (0.7° ± 0.08°C) per century globally since 1900 to 2016. Under higher scenarios, a global increase in average sea surface temperature of 4.9° ± 1.3°F (2.7° ± 0.7°C) is projected by 2100. (*Very high confidence*). (Ch. 13)

Global and Regional Sea Level Rise

Global mean sea level (GMSL) has risen by about 7–8 inches (about 16–21 cm) since 1900, with about 3 of those inches (about 7 cm) occurring since 1993 (very *high confidence*). (Ch. 12)

- Human-caused climate change has made a substantial contribution to GMSL rise since 1900 (*high confidence*), contributing to a rate of rise that is greater than during any preceding century in at least 2,800 years (*medium confidence*). (Ch. 12; Fig. ES.8)

- Relative to the year 2000, GMSL is *very likely* to rise by 0.3–0.6 feet (9–18 cm) by 2030, 0.5–1.2 feet (15–38 cm) by 2050, and 1.0–4.3 feet (30–130 cm) by 2100 (*very high confidence* in lower bounds; *medium confidence* in upper bounds for 2030 and 2050; *low* confidence in upper bounds for 2100). Future emissions pathways have little effect on projected GMSL rise in the first half of the century, but significantly affect projections for the second half of the century (*high confidence*). (Ch. 12)

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Recent Sea Level Rise Fastest for Over 2,000 Years

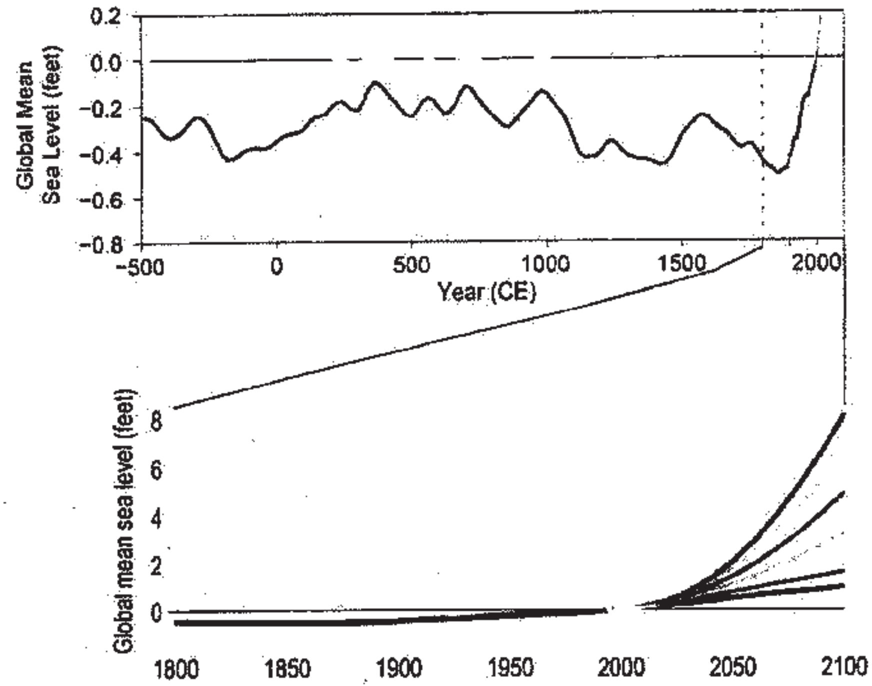

Figure ES.8: The top panel shows observed and reconstructed mean sea level for the last 2,500 years. The bottom panel shows projected mean sea level for six future scenarios. The six scenarios—spanning a range designed to inform a variety of decision makers—extend from a low scenario, consistent with continuation of the rate of sea level rise over the last quarter century, to an extreme scenario, assuming rapid mass loss from the Antarctic ice sheet. Note that the range on the vertical axis in the bottom graph is approximately ten times greater than in the top graph. *Based on Figure 12.2 and 12.4 in Chapter 12. See the main report for more details.*

- Emerging science regarding Antarctic ice sheet stability suggests that, for higher scenarios, a GMSL rise exceeding 8 feet (2.4 m) by 2100 is physically possible, although the probability of such an extreme outcome cannot currently be assessed. Regardless of emission pathway, it is *extremely likely* that GMSL rise will continue beyond 2100 (*high confidence*). (Ch. 12)

- Relative sea level rise in this century will vary along U.S. coastlines due, in part, to changes in Earth's gravitational field and rotation from melting of land ice, changes in ocean circulation, and vertical land motion (very high confidence). For almost all future GMSL rise scenarios, relative sea level rise is likely to be greater than the global average in the U.S. Northeast and the western Gulf of Mexico. In intermediate and low GMSL rise scenarios, relative sea level rise is likely to be less than the global average in much of the Pacific Northwest and Alaska. For high GMSL rise scenarios, relative sea level rise is likely to be higher than the global average along all U.S. coastlines outside Alaska. Almost all U.S. coastlines experience more than global mean sea level rise in response to Antarctic ice loss, and thus would be particularly affected under extreme GMSL rise scenarios involving substantial Antarctic mass loss (high confidence). (Ch. 12)

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Coastal Flooding

- As sea levels have risen, the number of tidal floods each year that cause minor impacts (also called "nuisance floods") have increased 5- to 10-fold since the 1960s in several U.S. coastal cities (*very high confidence*). Rates of increase are accelerating in over 25 Atlantic and Gulf Coast cities (*very high confidence*). Tidal flooding will continue increasing in depth, frequency, and extent this century (*very high confidence*). (Ch. 12)

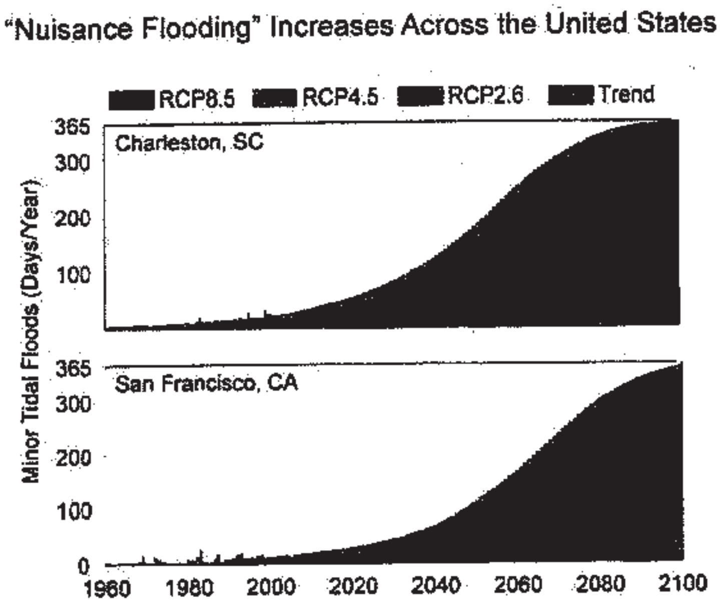

Figure ES. 9: Annual occurrences of tidal floods (days per year), also called sunny-day or nuisance flooding, have increased for some U.S. coastal cities. The figure shows historical exceedances (orange bars) for two of the locations—Charleston, SC and San Francisco, CA—and future projections through 2100. The projections are based upon the continuation of the historical trend (blue) and under median RCP2.6, 4.5 and 8.5 conditions. *From Figure 12.5, Chapter 12.*

- Assuming storm characteristics do not change, sea level rise will increase the frequency and extent of extreme flooding associated with coastal storms, such as hurricanes and nor'easters (very high confidence). A projected increase in the intensity of hurricanes in the North Atlantic (medium confidence) could increase the probability of extreme flooding along most of the U.S. Atlantic and Gulf Coast states beyond what would be projected based solely on relative sea level rise. However, there is low confidence in the projected increase in frequency of intense Atlantic hurricanes, and the associated flood risk amplification, and flood effects could be offset or amplified by such factors, such as changes in overall storm frequency or tracks. (Ch.12; Fig. ES. 9)

Global Ocean Circulation

- The potential slowing of the Atlantic meridional overturning circulation (AMOC; of which the Gulf Stream is one component)—as a result of increasing ocean heat content and freshwater-driven buoyancy changes—could have dramatic climate feedbacks as the ocean absorbs less heat and CO_2 from the atmosphere. This slowing would also affect the climates of North America and Europe. Any slowing documented to date cannot be directly tied to human-caused forcing, primarily due to lack of adequate observational data and to challenges

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in modeling ocean circulation changes. Under a higher scenario (RCP8.5), models show that the AMOC weakens over the 21st century (*low confidence*). (Ch. 13)

Global and Regional Ocean Acidification

The world's oceans are currently absorbing more than a quarter of the CO_2 emitted to the atmosphere annually from human activities, making them more acidic (*very high confidence*), with potential detrimental impacts to marine ecosystems. (Ch. 13)

- Higher-latitude systems typically have a lower buffering capacity against changing acidity, exhibiting seasonally corrosive conditions sooner than low-latitude systems. The rate of acidification is unparalleled in at least the past 66 million years (*medium confidence*). Under the higher scenario (RCP8.5), the global average surface ocean acidity is projected to increase by 100% to 150% (*high confidence*). (Ch. 13)

- Acidification is regionally greater than the global average along U.S. coastal systems as a result of upwelling (e.g., in the Pacific Northwest) (*high confidence*), changes in freshwater inputs (e.g., in the Gulf of Maine) (*medium confidence*), and nutrient input (e.g., in urbanized estuaries) (*high confidence*). (Ch. 13)

Ocean Oxygen

- Increasing sea surface temperatures, rising sea levels, and changing patterns of precipitation, winds, nutrients, and ocean circulation are contributing to overall declining oxygen concentrations at intermediate depths in various ocean locations and in many coastal areas. Over the last half century, major oxygen losses have occurred in inland seas, estuaries, and in the coastal and open ocean (*high confidence*). Ocean oxygen levels are projected to decrease by as much as 3.5% under the higher scenario (RCP8.5) by 2100 relative to preindustrial values (*high confidence*). (Ch. 13)

Climate Change in Alaska and across the Arctic Continues to Outpace Global Climate Change

Residents of Alaska are on the front lines of climate change. Crumbling buildings, roads, and bridges and eroding shorelines are commonplace. Accelerated melting of multiyear sea ice cover, mass loss from the Greenland Ice Sheet, reduced snow cover, and permafrost thawing are stark examples of the rapid changes occurring in the Arctic. Furthermore, because elements of the climate system are interconnected (see Box ES.1), changes in the Arctic influence climate conditions outside the Arctic.

Arctic Temperature Increases

Annual average near-surface air temperatures across Alaska and the Arctic have increased over the last 50 years at a rate more than twice as fast as the global average temperature. (*Very high confidence*) (Ch. 11)

- Rising Alaskan permafrost temperatures are causing permafrost to thaw and become more discontinuous; this process releases additional carbon dioxide and methane resulting in additional warming (*high confidence*). The overall magnitude of the permafrost-carbon feedback is uncertain (Ch.2); however, it is clear that these emissions have the potential to compromise the ability to limit global temperature increases. (Ch. 11)

- Atmospheric circulation patterns connect the climates of the Arctic and the contiguous United States. Evidenced by recent record warm temperatures in the Arctic and emerging science, the midlatitude circulation has influenced observed arctic temperatures and sea ice (*high confidence*). However, confidence is low regarding whether or by what mechanisms observed arctic warming may have influenced the midlatitude circulation and weather patterns over the continental United States. The influence of arctic changes on U.S. weather over the coming decades remains an open question with the potential for significant impact. (Ch. 11)

Arctic Land Ice Loss

- Arctic land ice loss observed in the last three decades continues, in some cases accelerating (*very high confidence*). It is *virtually certain* that Alaska glaciers have lost mass over the last 50 years, with each year since 1984 showing an annual average ice mass less than the previous year. Over the satellite record, average ice mass loss from Greenland was −269 Gt per year between April 2002 and April 2016, accelerating in recent years (*high confidence*). (Ch. 11)

Arctic Sea Ice Loss

Since the early 1980s, annual average arctic sea ice has decreased in extent between 3.5% and 4.1% per decade, has become thinner by between 4.3 and 7.5 feet, and is melting at least 15 more days each year. September sea ice extent has decreased between 10.7% and 15.9% per decade. (*Very high confidence*) (Ch. 11)

- Arctic sea ice loss is expected to continue through the 21st century, *very likely* resulting in nearly sea ice-free late summers by the 2040s (*very high confidence*). (Ch. 11)

- It is *very likely* that human activities have contributed to observed arctic surface temperature warming, sea ice loss, glacier mass loss, and northern hemisphere snow extent decline (*high confidence*). (Ch. 11)

Multiyear Sea Ice Has Declined Dramatically

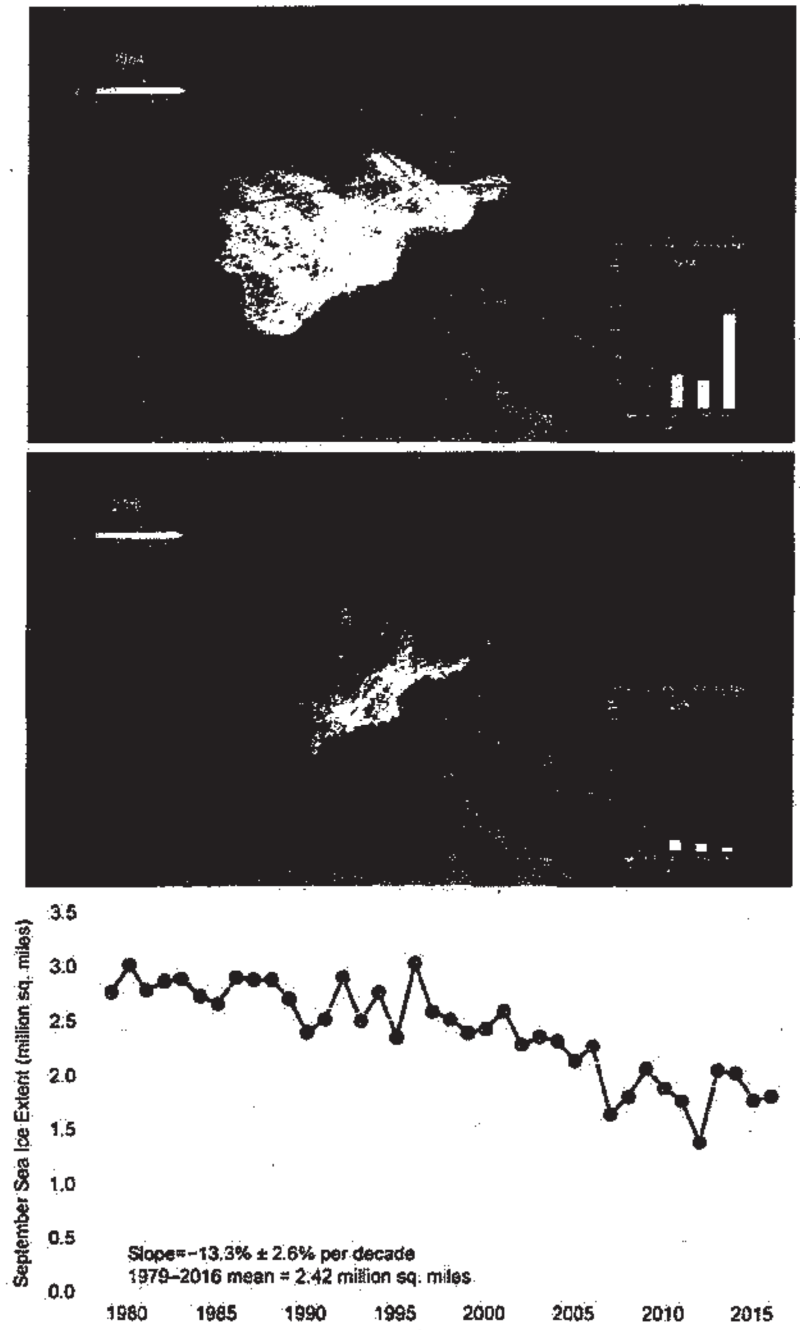

Figure ES.10: September sea ice extent and age shown for (top) 1984 and (middle) 2016, illustrating significant reductions in sea ice extent and age (thickness). The bar graph in the lower right of each panel illustrates the sea ice area (unit: million km²) covered within each age category (> 1 year), and the green bars represent the maximum extent for each age range during the record. The year 1984 is representative of September sea ice characteristics during the 1980s. The years 1984 and 2016 are selected as endpoints in the time series; a movie of the complete time series is available at http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4489. (bottom) The satellite-era arctic sea ice areal extent trend from 1979 to 2016 for September (unit: million mi²). *From Figure 11.1 in Chapter 11.*

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Limiting Globally Averaged Warming to 2°C (3.6°F) Will Require Major Reductions in Emissions

Human activities are now the dominant cause of the observed trends in climate. For that reason, future climate projections are based on scenarios of how human activities will continue to affect the climate over the remainder of this century and beyond (see Sidebar: Scenarios Used in this Assessment). There remains significant uncertainty about future emissions due to changing economic, political, and demographic factors. For that reason, this report quantifies possible climate changes for a broad set of plausible future scenarios through the end of the century. (Ch. 2, 4, 10, 14)

The observed increase in global carbon emissions over the past 15–20 years has been consistent with higher scenarios (e.g., RCP8.5) (*very high confidence*). In 2014 and 2015, emission growth rates slowed as economic growth became less carbon-intensive (*medium confidence*). Even if this slowing trend continues, however, it is not yet at a rate that would limit the increase in the global average temperature to well below 3.6°F (2°C) above preindustrial levels (*high confidence*). (Ch. 4)

- Global mean atmospheric carbon dioxide (CO_2) concentration has now passed 400 ppm, a level that last occurred about 3 million years ago, when global average temperature and sea level were significantly higher than today (*high confidence*). Continued growth in CO_2 emissions over this century and beyond would lead to an atmospheric concentration not experienced in tens of millions of years (*medium confidence*). The present-day emissions rate of nearly 10 GtC per year suggests that there is no climate analog for this century any time in at least the last 50 million years (*medium confidence*). (Ch. 4)

- Warming and associated climate effects from CO_2 emissions persist for decades to millennia. In the near-term, changes in climate are determined by past and present greenhouse gas emissions modified by natural variability. Reducing net emissions of CO_2 is necessary to limit near-term climate change and long-term warming. Other greenhouse gases (e.g., methane) and black carbon aerosols exert stronger warming effects than CO_2 on a per ton basis, but they do not persist as long in the atmosphere (Ch. 2); therefore, mitigation of non-CO_2 species contributes substantially to near-term cooling benefits but cannot be relied upon for ultimate stabilization goals. (*Very high confidence*) (Ch. 14)

Choices made today will determine the magnitude of climate change risks beyond the next few decades. (Ch. 4, 14)

- Stabilizing global mean temperature to less than 3.6°F (2°C) above preindustrial levels requires substantial reductions in net global CO_2 emissions prior to 2040 relative to present-day values and likely requires net emissions to become zero or possibly negative later in the century. After accounting for the temperature effects of non-CO_2 species, cumulative global CO_2 emissions must stay below about 800 GtC in order to provide a two-thirds likelihood of preventing 3.6°F (2°C) of

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warming. Given estimated cumulative emissions since 1870, no more than approximately 230 GtC may be emitted in the future in order to remain under this temperature limit. Assuming global emissions are equal to or greater than those consistent with the RCP4.5 scenario, this cumulative carbon threshold would be exceeded in approximately two decades. (Ch. 14)

- Achieving global greenhouse gas emissions reductions before 2030 consistent with targets and actions announced by governments in the lead up to the 2015 Paris climate conference would hold open the possibility of meeting the long-term temperature goal of limiting global warming to 3.6°F (2°C) above preindustrial levels, whereas there would be virtually no chance if net global emissions followed a pathway well above those implied by country announcements. Actions in the announcements are, by themselves, insufficient to meet a 3.6°F (2°C) goal; the likelihood of achieving that depends strongly on the magnitude of global emissions reductions after 2030. (*High confidence*) (Ch. 14)

- Climate intervention or geoengineering strategies such as solar radiation management are measures that attempt to limit or reduce global temperature increases. Further assessments of the technical feasibilities, costs, risks, co-benefits, and governance challenges of climate intervention or geoengineering strategies, which are as yet unproven at scale, are a necessary step before judgments about the benefits and risks of these approaches can be made with high confidence. (*High confidence*) (Ch. 14)

- In recent decades, land-use and land-cover changes have turned the terrestrial biosphere (soil and plants) into a net "sink" for carbon (drawing down carbon from the atmosphere), and this sink has steadily increased since 1980 (*high confidence*). Because of the uncertainty in the trajectory of land cover, the possibility of the land becoming a net carbon source cannot be excluded (*very high confidence*). (Ch. 10)

There is a Significant Possibility for Unanticipated Changes

Humanity's effect on the Earth system, through the large-scale combustion of fossil fuels and widespread deforestation and the resulting release of carbon dioxide (CO_2) into the atmosphere, as well as through emissions of other greenhouse gases and radiatively active substances from human activities, is unprecedented. There is significant potential for humanity's effect on the planet to result in unanticipated surprises and a broad consensus that the further and faster the Earth system is pushed towards warming, the greater the risk of such surprises.

There are at least two types of potential surprises: *compound events*, where multiple extreme climate events occur simultaneously or sequentially (creating greater overall impact), and *critical threshold* or *tipping point events*, where some threshold is crossed in the climate system (that leads to large impacts). The probability of such surprises—some of which may be abrupt and/or irreversible—as well as other more predictable but difficult-to-manage impacts, increases as the influence of human activities on the climate system increases. (Ch. 15)

Unanticipated and difficult or impossible-to-manage changes in the climate system are possible throughout the next century as critical thresholds are crossed and/or multiple climate-related extreme events occur simultaneously. (Ch. 15)

- Positive feedbacks (self-reinforcing cycles) within the climate system have the potential to accelerate human-induced climate change and even shift the Earth's climate system, in part or in whole, into new states that are very different from those experienced in the recent past (for example, ones with greatly diminished ice sheets or different large-scale patterns of atmosphere or ocean circulation). Some feedbacks and potential state shifts can be modeled and quantified; others can be modeled or identified but not quantified; and some are probably still unknown. (*Very high confidence* in the potential for state shifts and in the incompleteness of knowledge about feedbacks and potential state shifts). (Ch. 15)

- The physical and socioeconomic impacts of compound extreme events (such as simultaneous heat and drought, wildfires associated with hot and dry conditions, or flooding associated with high precipitation on top of snow or waterlogged ground) can be greater than the sum of the parts (*very high confidence*). Few analyses consider the spatial or temporal correlation between extreme events. (Ch. 15)

- While climate models incorporate important climate processes that can be well quantified, they do not include all of the processes that can contribute to feedbacks (Ch. 2), compound extreme events, and abrupt and / or irreversible changes. For this reason, future changes outside the range projected by climate models cannot be ruled out (*very high confidence*). Moreover, the systematic tendency of climate models to underestimate temperature change during warm paleoclimates suggests that climate models are more likely to underestimate than to overestimate the amount of long-term future change (*medium confidence*). (Ch. 15)

Box ES.2: A Summary of Advances Since NCA3

Advances in scientific understanding and scientific approach, as well as developments in global policy, have occurred since NCA3. A detailed summary of these advances can be found at the end of Chapter 1: Our Globally Changing Climate. Highlights of what aspects are either especially strengthened or are emerging in the current findings include

- ***Detection and attribution***: Significant advances have been made in the attribution of the human influence for individual climate and weather extreme events since NCA3. (Chapters 3, 6, 7, 8).

- ***Atmospheric circulation and extreme events***: The extent to which atmospheric circulation in the midlatitudes is changing or is projected to change, possibly in ways not captured by current climate models, is a new important area of research. (Chapters 5, 6, 7).

- ***Increased understanding of specific types of extreme events***: How climate change may affect specific types of extreme events in the United States is another key area where scientific understanding has advanced. (Chapter 9).

- ***High-resolution global climate model simulations***: As computing resources have grown, multidecadal simulations of global climate models are now being conducted at horizontal resolutions on the order of 15 miles (25 km) that provide more realistic characterization of intense weather systems, including hurricanes. (Chapter 9).

- ***Oceans and coastal waters***: Ocean acidification, warming, and oxygen loss are all increasing, and scientific understanding of the severity of their impacts is growing. Both oxygen loss and acidification may be magnified in some U.S. coastal waters relative to the global average, raising the risk of serious ecological and economic consequences. (Chapters 2, 13).

- ***Local sea level change projections***: For the first time in the NCA process, sea level rise projections incorporate geographic variation based on factors such as local land subsidence, ocean currents, and changes in Earth's gravitational field. (Chapter 12).

- ***Accelerated ice-sheet loss***: New observations from many different sources confirm that ice-sheet loss is accelerating. Combining observations with simultaneous advances in the physical understanding of ice sheets leads to the conclusion that up to 8.5 feet of global sea level rise is possible by 2100 under a higher scenario (RCP8.5), up from 6.6 feet in NCA3. (Chapter 12).

- ***Low sea-ice areal extent***: The annual arctic sea ice extent minimum for 2016 relative to the long-term record was the second lowest on record. The arctic sea ice minimums in 2014 and 2015 were also amongst the lowest on record. Since 1981, the sea ice minimum has decreased by 13.3% per decade, more than 46% over the 35 years. The annual arctic sea ice maximum in March 2017 was the lowest maximum areal extent on record. (Chapter 11).

- ***Potential surprises***: Both large-scale state shifts in the climate system (sometimes called "tipping points") and compound extremes have the potential to generate unanticipated climate surprises. The further the Earth system departs from historical climate forcings, and the more the climate changes, the greater the potential for these surprises. (Chapter 15).

- ***Mitigation***: This report discusses some important aspects of climate science that are relevant to long-term temperature goals and different mitigation scenarios, including those implied by government announcements for the Paris Agreement. (Chapters 4, 14).

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Confidence Level	
Very High	Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
High	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Likelihood	
Virtually Certain	99%–100%
Extremely Likely	95%–100%
Very Likely	90%–100%
Likely	66%–100%
About as Likely as Not	33%–66%
Unlikely	0%–33%
Very Unlikely	0%–10%
Extremely Unlikely	0%–5%
Exceptionally Unlikely	0%–1%

Confidence levels and likelihood statements used in the Executive Summary. As an example, regarding "likely," a 66–100% probability can be interpreted as a likelihood of greater than 2 out of 3 chances for the statement to be certain or true. Not all likelihoods are used in the report.

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Tab E

Summary Findings

NCA4 Summary Findings

These Summary Findings represent a high-level synthesis of the material in the underlying report. The findings consolidate Key Messages and supporting evidence from 16 national-level topic chapters, 10 regional chapters, and 2 chapters that focus on societal response strategies (mitigation and adaptation). Unless otherwise noted, qualitative statements regarding future conditions in these Summary Findings are broadly applicable across the range of different levels of future climate change and associated impacts considered in this report.

1. Communities

Climate change creates new risks and exacerbates existing vulnerabilities in communities across the United States, presenting growing challenges to human health and safety, quality of life, and the rate of economic growth.

The impacts of climate change are already being felt in communities across the country. More frequent and intense extreme weather and climate-related events, as well as changes in average climate conditions, are expected to continue to damage infrastructure, ecosystems, and social systems that provide essential benefits to communities. Future climate change is expected to further disrupt many areas of life, exacerbating existing challenges to prosperity posed by aging and deteriorating infrastructure, stressed ecosystems, and economic inequality. Impacts within and across regions will not be distributed equally. People who are already vulnerable, including lower-income and other marginalized communities, have lower capacity to prepare for and cope with extreme weather and climate-related events and are expected to experience greater impacts. Prioritizing adaptation actions for the most vulnerable populations would contribute to a more equitable future within and across communities. Global action to significantly cut greenhouse gas emissions can substantially reduce climate-related risks and increase opportunities for these populations in the longer term.

2. Economy

Without substantial and sustained global mitigation and regional adaptation efforts, climate change is expected to cause growing losses to American infrastructure and property and impede the rate of economic growth over this century.

In the absence of significant global mitigation action and regional adaptation efforts, rising temperatures, sea level rise, and changes in extreme events are expected to increasingly disrupt and damage critical infrastructure and property, labor productivity, and the vitality of our communities. Regional economies and industries that depend on natural resources and favorable climate conditions, such as agriculture, tourism, and fisheries, are vulnerable to the growing impacts of climate change. Rising temperatures are projected to reduce the efficiency of power generation while increasing energy demands, resulting in higher electricity costs. The impacts of climate change beyond our borders are expected to increasingly affect our trade and economy, including import and export prices and U.S. businesses

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with overseas operations and supply chains. Some aspects of our economy may see slight near-term improvements in a modestly warmer world. However, the continued warming that is projected to occur without substantial and sustained reductions in global greenhouse gas emissions is expected to cause substantial net damage to the U.S. economy throughout this century, especially in the absence of increased adaptation efforts. With continued growth in emissions at historic rates, annual losses in some economic sectors are projected to reach hundreds of billions of dollars by the end of the century—more than the current gross domestic product (GDP) of many U.S. states.

3. Interconnected Impacts

Climate change affects the natural, built, and social systems we rely on individually and through their connections to one another. These interconnected systems are increasingly vulnerable to cascading impacts that are often difficult to predict, threatening essential services within and beyond the Nation's borders.

Climate change presents added risks to interconnected systems that are already exposed to a range of stressors such as aging and deteriorating infrastructure, land-use changes, and population growth. Extreme weather and climate-related impacts on one system can result in increased risks or failures in other critical systems, including water resources, food production and distribution, energy and transportation, public health, international trade, and national security. The full extent of climate change risks to interconnected systems, many of which span regional and national boundaries, is often greater than the sum of risks to individual sectors. Failure to anticipate interconnected impacts can lead to missed opportunities for effectively managing the risks of climate change and can also lead to management responses that increase risks to other sectors and regions. Joint planning with stakeholders across sectors, regions, and jurisdictions can help identify critical risks arising from interaction among systems ahead of time.

4. Actions to Reduce Risks

Communities, governments, and businesses are working to reduce risks from and costs associated with climate change by taking action to lower greenhouse gas emissions and implement adaptation strategies. While mitigation and adaptation efforts have expanded substantially in the last four years, they do not yet approach the scale considered necessary to avoid substantial damages to the economy, environment, and human health over the coming decades.

Future risks from climate change depend primarily on decisions made today. The integration of climate risk into decision-making and the implementation of adaptation activities have significantly increased since the Third National Climate Assessment in 2014, including in areas of financial risk reporting, capital investment planning, development of engineering standards, military planning, and disaster risk management. Transformations in the energy sector—including the displacement of coal by natural gas and increased deployment of

renewable energy—along with policy actions at the national, regional, state, and local levels are reducing greenhouse gas emissions in the United States. While these adaptation and mitigation measures can help reduce damages in a number of sectors, this assessment shows that more immediate and substantial global greenhouse gas emissions reductions, as well as regional adaptation efforts, would be needed to avoid the most severe consequences in the long term. Mitigation and adaptation actions also present opportunities for additional benefits that are often more immediate and localized, such as improving local air quality and economies through investments in infrastructure. Some benefits, such as restoring ecosystems and increasing community vitality, may be harder to quantify.

5. Water

The quality and quantity of water available for use by people and ecosystems across the country are being affected by climate change, increasing risks and costs to agriculture, energy production, industry, recreation, and the environment.

Rising air and water temperatures and changes in precipitation are intensifying droughts, increasing heavy downpours, reducing snowpack, and causing declines in surface water quality, with varying impacts across regions. Future warming will add to the stress on water supplies and adversely impact the availability of water in parts of the United States. Changes in the relative amounts and timing of snow and rainfall are leading to mismatches between water availability and needs in some regions, posing threats to, for example, the future reliability of hydropower production in the Southwest and the Northwest. Groundwater depletion is exacerbating drought risk in many parts of the United States, particularly in the Southwest and Southern Great Plains. Dependable and safe water supplies for U.S. Caribbean, Hawai'i, and U.S.-Affiliated Pacific Island communities are threatened by drought, flooding, and saltwater contamination due to sea level rise. Most U.S. power plants rely on a steady supply of water for cooling, and operations are expected to be affected by changes in water availability and temperature increases. Aging and deteriorating water infrastructure, typically designed for past environmental conditions, compounds the climate risk faced by society. Water management strategies that account for changing climate conditions can help reduce present and future risks to water security, but implementation of such practices remains limited.

6. Health

Impacts from climate change on extreme weather and climate-related events, air quality, and the transmission of disease through insects and pests, food, and water increasingly threaten the health and well-being of the American people, particularly populations that are already vulnerable.

Changes in temperature and precipitation are increasing air quality and health risks from wildfire and ground-level ozone pollution. Rising air and water temperatures and more intense extreme events are expected to increase exposure to waterborne and foodborne diseases, affecting food and water safety. With continued warming, cold-related deaths are

projected to decrease and heat-related deaths are projected to increase; in most regions, increases in heat-related deaths are expected to outpace reductions in cold-related deaths. The frequency and severity of allergic illnesses, including asthma and hay fever, are expected to increase as a result of a changing climate. Climate change is also projected to alter the geographic range and distribution of disease-carrying insects and pests, exposing more people to ticks that carry Lyme disease and mosquitoes that transmit viruses such as Zika, West Nile, and dengue, with varying impacts across regions. Communities in the Southeast, for example, are particularly vulnerable to the combined health impacts from vector-borne disease, heat, and flooding. Extreme weather and climate-related events can have lasting mental health consequences in affected communities, particularly if they result in degradation of livelihoods or community relocation. Populations including older adults, children, low-income communities, and some communities of color are often disproportionately affected by, and less resilient to, the health impacts of climate change. Adaptation and mitigation policies and programs that help individuals, communities, and states prepare for the risks of a changing climate reduce the number of injuries, illnesses, and deaths from climate-related health outcomes.

7. Indigenous Peoples

Climate change increasingly threatens Indigenous communities' livelihoods, economies, health, and cultural identities by disrupting interconnected social, physical, and ecological systems.

Many Indigenous peoples are reliant on natural resources for their economic, cultural, and physical well-being and are often uniquely affected by climate change. The impacts of climate change on water, land, coastal areas, and other natural resources, as well as infrastructure and related services, are expected to increasingly disrupt Indigenous peoples' livelihoods and economies, including agriculture and agroforestry, fishing, recreation, and tourism. Adverse impacts on subsistence activities have already been observed. As climate changes continue, adverse impacts on culturally significant species and resources are expected to result in negative physical and mental health effects. Throughout the United States, climate-related impacts are causing some Indigenous peoples to consider or actively pursue community relocation as an adaptation strategy, presenting challenges associated with maintaining cultural and community continuity. While economic, political, and infrastructure limitations may affect these communities' ability to adapt, tightly knit social and cultural networks present opportunities to build community capacity and increase resilience. Many Indigenous peoples are taking steps to adapt to climate change impacts structured around self-determination and traditional knowledge, and some tribes are pursuing mitigation actions through development of renewable energy on tribal lands.

8. Ecosystems and Ecosystem Services

Ecosystems and the benefits they provide to society are being altered by climate change, and these impacts are projected to continue. Without substantial and sustained reductions in global greenhouse gas emissions, transformative impacts on some ecosystems will occur; some coral reef and sea ice ecosystems are already experiencing such transformational changes.

Many benefits provided by ecosystems and the environment, such as clean air and water, protection from coastal flooding, wood and fiber, crop pollination, hunting and fishing, tourism, cultural identities, and more will continue to be degraded by the impacts of climate change. Increasing wildfire frequency, changes in insect and disease outbreaks, and other stressors are expected to decrease the ability of U.S. forests to support economic activity, recreation, and subsistence activities. Climate change has already had observable impacts on biodiversity, ecosystems, and the benefits they provide to society. These impacts include the migration of native species to new areas and the spread of invasive species. Such changes are projected to continue, and without substantial and sustained reductions in global greenhouse gas emissions, extinctions and transformative impacts on some ecosystems cannot be avoided in the long term. Valued aspects of regional heritage and quality of life tied to ecosystems, wildlife, and outdoor recreation will change with the climate, and as a result, future generations can expect to experience and interact with the natural environment in ways that are different from today. Adaptation strategies, including prescribed burning to reduce fuel for wildfire, creation of safe havens for important species, and control of invasive species, are being implemented to address emerging impacts of climate change. While some targeted response actions are underway, many impacts, including losses of unique coral reef and sea ice ecosystems, can only be avoided by significantly reducing global emissions of carbon dioxide and other greenhouse gases.

9. Agriculture and Food

Rising temperatures, extreme heat, drought, wildfire on rangelands, and heavy downpours are expected to increasingly disrupt agricultural productivity in the United States. Expected increases in challenges to livestock health, declines in crop yields and quality, and changes in extreme events in the United States and abroad threaten rural livelihoods, sustainable food security, and price stability.

Climate change presents numerous challenges to sustaining and enhancing crop productivity, livestock health, and the economic vitality of rural communities. While some regions (such as the Northern Great Plains) may see conditions conducive to expanded or alternative crop productivity over the next few decades, overall, yields from major U.S. crops are expected to decline as a consequence of increases in temperatures and possibly changes in water availability, soil erosion, and disease and pest outbreaks. Increases in temperatures during the growing season in the Midwest are projected to be the largest contributing factor to declines in the productivity of U.S. agriculture. Projected increases in extreme heat conditions are expected to lead to further heat stress for livestock, which can result in large economic

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losses for producers. Climate change is also expected to lead to large-scale shifts in the availability and prices of many agricultural products across the world, with corresponding impacts on U.S. agricultural producers and the U.S. economy. These changes threaten future gains in commodity crop production and put rural livelihoods at risk. Numerous adaptation strategies are available to cope with adverse impacts of climate variability and change on agricultural production. These include altering what is produced, modifying the inputs used for production, adopting new technologies, and adjusting management strategies. However, these strategies have limits under severe climate change impacts and would require sufficient long- and short-term investment in changing practices.

10. Infrastructure

Our Nation's aging and deteriorating infrastructure is further stressed by increases in heavy precipitation events, coastal flooding, heat, wildfires, and other extreme events, as well as changes to average precipitation and temperature. Without adaptation, climate change will continue to degrade infrastructure performance over the rest of the century, with the potential for cascading impacts that threaten our economy, national security, essential services, and health and well-being.

Climate change and extreme weather events are expected to increasingly disrupt our Nation's energy and transportation systems, threatening more frequent and longer-lasting power outages, fuel shortages, and service disruptions, with cascading impacts on other critical sectors. Infrastructure currently designed for historical climate conditions is more vulnerable to future weather extremes and climate change. The continued increase in the frequency and extent of high-tide flooding due to sea level rise threatens America's trillion-dollar coastal property market and public infrastructure, with cascading impacts to the larger economy. In Alaska, rising temperatures and erosion are causing damage to buildings and coastal infrastructure that will be costly to repair or replace, particularly in rural areas; these impacts are expected to grow without adaptation. Expected increases in the severity and frequency of heavy precipitation events will affect inland infrastructure in every region, including access to roads, the viability of bridges, and the safety of pipelines. Flooding from heavy rainfall, storm surge, and rising high tides is expected to compound existing issues with aging infrastructure in the Northeast. Increased drought risk will threaten oil and gas drilling and refining, as well as electricity generation from power plants that rely on surface water for cooling. Forward-looking infrastructure design, planning, and operational measures and standards can reduce exposure and vulnerability to the impacts of climate change and reduce energy use while providing additional near-term benefits, including reductions in greenhouse gas emissions.

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11. Oceans and Coasts

Coastal communities and the ecosystems that support them are increasingly threatened by the impacts of climate change. Without significant reductions in global greenhouse gas emissions and regional adaptation measures, many coastal regions will be transformed by the latter part of this century, with impacts affecting other regions and sectors. Even in a future with lower greenhouse gas emissions, many communities are expected to suffer financial impacts as chronic high-tide flooding leads to higher costs and lower property values.

Rising water temperatures, ocean acidification, retreating arctic sea ice, sea level rise, high-tide flooding, coastal erosion, higher storm surge, and heavier precipitation events threaten our oceans and coasts. These effects are projected to continue, putting ocean and marine species at risk, decreasing the productivity of certain fisheries, and threatening communities that rely on marine ecosystems for livelihoods and recreation, with particular impacts on fishing communities in Hawai'i and the U.S.-Affiliated Pacific Islands, the U.S. Caribbean, and the Gulf of Mexico. Lasting damage to coastal property and infrastructure driven by sea level rise and storm surge is expected to lead to financial losses for individuals, businesses, and communities, with the Atlantic and Gulf Coasts facing above-average risks. Impacts on coastal energy and transportation infrastructure driven by sea level rise and storm surge have the potential for cascading costs and disruptions across the country. Even if significant emissions reductions occur, many of the effects from sea level rise over this century—and particularly through mid-century—are already locked in due to historical emissions, and many communities are already dealing with the consequences. Actions to plan for and adapt to more frequent, widespread, and severe coastal flooding, such as shoreline protection and conservation of coastal ecosystems, would decrease direct losses and cascading impacts on other sectors and parts of the country. More than half of the damages to coastal property are estimated to be avoidable through well-timed adaptation measures. Substantial and sustained reductions in global greenhouse gas emissions would also significantly reduce projected risks to fisheries and communities that rely on them.

12. Tourism and Recreation

Outdoor recreation, tourist economies, and quality of life are reliant on benefits provided by our natural environment that will be degraded by the impacts of climate change in many ways.

Climate change poses risks to seasonal and outdoor economies in communities across the United States, including impacts on economies centered around coral reef-based recreation, winter recreation, and inland water-based recreation. In turn, this affects the well-being of the people who make their living supporting these economies, including rural, coastal, and Indigenous communities. Projected increases in wildfire smoke events are expected to impair outdoor recreational activities and visibility in wilderness areas. Declines in snow and ice cover caused by warmer winter temperatures are expected to negatively impact the winter recreation industry in the Northwest, Northern Great Plains, and the Northeast. Some fish, birds, and mammals are expected to shift where they live as a result of climate change,

with implications for hunting, fishing, and other wildlife-related activities. These and other climate-related impacts are expected to result in decreased tourism revenue in some places and, for some communities, loss of identity. While some new opportunities may emerge from these ecosystem changes, cultural identities and economic and recreational opportunities based around historical use of and interaction with species or natural resources in many areas are at risk. Proactive management strategies, such as the use of projected stream temperatures to set priorities for fish conservation, can help reduce disruptions to tourist economies and recreation.

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STATEMENT FOR THE RECORD

WORLDWIDE THREAT ASSESSMENT
OF THE US INTELLIGENCE COMMUNITY

Daniel R. Coats
Director of National Intelligence

Senate Select Committee on Intelligence

29 JANUARY 2019

Environment and Climate Change

Global environmental and ecological degradation, as well as climate change, are likely to fuel competition for resources, economic distress, and social discontent through 2019 and beyond. Climate hazards such as extreme weather, higher temperatures, droughts, floods, wildfires, storms, sea level rise, soil degradation, and acidifying oceans are intensifying, threatening infrastructure, health, and water and food security. Irreversible damage to ecosystems and habitats will undermine the economic benefits they provide, worsened by air, soil, water, and marine pollution.

- Extreme weather events, many worsened by accelerating sea level rise, will particularly affect urban coastal areas in South Asia, Southeast Asia, and the Western Hemisphere. Damage to communication, energy, and transportation infrastructure could affect low-lying military bases, inflict economic costs, and cause human displacement and loss of life.

- Changes in the frequency and variability of heat waves, droughts, and floods—combined with poor governance practices—are increasing water and food insecurity around the world, increasing the risk of social unrest, migration, and interstate tension in countries such as Egypt, Ethiopia, Iraq, and Jordan.

- Diminishing Arctic sea ice may increase competition—particularly with Russia and China—over access to sea routes and natural resources. Nonetheless, Arctic states have maintained mostly positive cooperation in the region through the Arctic Council and other multilateral mechanisms, a trend we do not expect to change in the near term. Warmer temperatures and diminishing sea ice are reducing the high cost and risks of some commercial activities and are attracting new players to the resource-rich region. In 2018, the minimum sea ice extent in the Arctic was 25 percent below the 30-year average from 1980 to 2010.